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Workshop on Research Needs in Wind Engineering

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ABSTRACT

This report presents findings and recommendations developed at a workshop on research needs in wind engineering convened at Gaithersburg, Maryland, on September 12-13, 1994. Representatives from universities, the private sector, and Federal agencies currently engaged in or otherwise supporting wind engineering research presented program overviews and participated in working group sessions addressing various aspects of wind engineering research and wind disaster mitigation. Research needs and topics for technology transfer were identified and prioritized. It was concluded that current funding of wind engineering research in the United States falls far short of what is needed to effectively address the problem of spiraling losses due to wind damage. There is, however, considerable wind engineering knowledge now available for implementation by the model building codes and by the building industry in general. This implementation will require coordination of the efforts of industry, universities, and State and Federal agencies, along with appropriate funding.

Keywords: building technology; codes and standards; hurricanes; meteorology; technology transfer: tornadoes; wind climate; wind disasters; wind engineering; wind research; wind tunnels.

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EXECUTIVE SUMMARY

Over the past decade wind damage to the built environment has been increasing at an alarming rate with insured catastrophe losses in the United States amounting to approximately $41 billion from 1986 to 1993, compared with $6.18 billion for all other natural hazards combined. In two recent events alone, Hurricane Hugo in 1989 and Hurricane Andrew in 1992, property losses amounted to $9 billion and $30 billion, respectively. Among the reasons for this trend are increased development in high-risk areas, the relatively low priority given to severe storm research and extreme wind climatology by the meteorological research community, neglect of secondary structures such as single-family dwellings and light commercial buildings by the wind engineering research community and the structural design profession, the rapid introduction of new and unproven building materials and construction practices, inadequate inspection and code enforcement, and the failure of building officials and the building industry to implement existing knowledge on wind loads. If any real progress is to be made in mitigating wind damage, each of these issues must be addressed.

The motivation for this workshop was the bringing together of representatives of institutions currently engaged in wind engineering research to determine how best to proceed, given the fact that the current low level of funding available for such research is likely to obtain over the foreseeable future. Specifically, the objective was to identify areas of research that can be expected to have a significant impact on wind damage mitigation, ongoing research activities and existing research facilities in the participating universities and Federal agencies, and opportunities to increase the effectiveness of research activities through university/agency collaboration. To this end, the following issues served as a workshop focus:

- What is being done now in wind engineering research?
- What are the critical issues in wind engineering and how can we best address them?
- How can we increase collaboration among the universities and the Federal agencies?
- Approximately, what is the current level of funding in wind engineering research?
- What level of research effort is needed and what will it cost?
- Where do we go from here; is there a need for another workshop?

To seek answers to these questions, the first morning of the workshop was devoted to the presentation of program overviews by the workshop participants, and overviews submitted by the workshop participants are included in this workshop proceedings. The remainder of the workshop was devoted to working group deliberations and the presentation at a final plenary session of the findings and recommendations developed by the working groups. Organization of the working groups was as follows:

WG 1 Meteorology, Extreme-wind climatology, Instrumentation, Post-disaster assessments, Databases.

WG 2 Wind-tunnel modeling, Full-scale studies, Pressure and force coefficients, Databases.

WG 3 Materials and component testing, Post-disaster assessments.

WG 4 Structural modeling and analysis, Reliability, Risk-consistent design, Cost-benefit studies.

Specific findings and recommendations developed in the course of the workshop are included in the individual working group reports. Current funding of wind engineering research in the United States is less than $1 million per year, a small fraction of the $25 million to $30 million believed necessary to arrest and reverse the trend of increasing wind damage to the built environment. Over the short term, there is considerable wind engineering knowledge now available and ready for implementation by the model building codes and the building industry in general. However, appropriate funding and the active participation and support of building officials, model building code groups, and the building industry will be required if this technology transfer is to come about. To this end, additional workshops involving the private sector, university researchers, and State and Federal agencies are to be encouraged.

With a firm commitment to adequate funding levels, it is believed that many of the critical areas of wind engineering can be addressed within a period of five years. However, areas such as extreme wind climatology and full-scale observations under extreme wind conditions are inherently long-term ventures.

WORKSHOP ON RESEARCH NEEDS IN WIND ENGINEERING

GAITHERSBURG, MARYLAND

SEPTEMBER 12-13, 1994

1.0 INTRODUCTION

Over the past decade wind damage to the built environment has been increasing at an alarming rate. In the period from 1986 to 1993, extreme wind events caused approximately $41 billion in insured catastrophe losses, compared with $6.18 billion for all other natural hazards combined.[1] In two recent events alone, Hurricane Hugo[2] in 1989 and Hurricane Andrew[3] in 1992, property losses amounted to $9 billion and $30 billion, respectively. Among the reasons for this trend are increased development in high-risk areas, neglect of severe storm research and extreme wind climatology by the meteorological research community, neglect of secondary structures such as single-family dwellings by the wind engineering research community and the structural design profession, the rapid introduction of new and unproven building materials and construction practices, and the failure of building officials and the building industry to implement existing knowledge on wind loads. If any real progress is to be made in mitigating wind damage, each of these issues must be addressed.

2.0 BACKGROUND

On June 23-24, 1994, the Private Enterprise/Government Interactions (PEGI) Working Group of the Committee on the Environment and Natural Resources, National Council on Science and Technology, jointly with the Insurance Institute for Property Loss Reduction, hosted a workshop in Golden, Colorado, titled "Reducing Losses in Wind Disasters: The Role of Government and Private Industry." The workshop was attended by approximately 50 individuals representing private industry, universities, model building code groups, and State and Federal agencies. Workshop participants were organized into four working groups charged with addressing the following topics:

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[1] Dan D. McLean, "Chairman's Report to the Annual Meeting," First Annual Meeting of Insurance Institute for Property Loss Reduction, Seattle, WA, October 12, 1994.

[2] "Hurricane Hugo, September 10-22, 1989," Natural Disaster Survey Report, National Weather Service, NOAA, Silver Spring, MD, May 1990.

[3] "Hurricane Andrew: South Florida and Louisiana, August 23-25, 1992," Natural Disaster Survey Report, National Weather Service, NOAA, Silver Spring, MD, May 1993.

Building Codes - Enforcement Issues
Building Codes - Relationship Between National Standards and Statewide Codes
Assumptions for Damage Surveys
Technologies for Improved Wind Measurements

A final report on the PEGI workshop findings and recommendations is in preparation and, therefore, this report was not available at the time of the workshop held in Gaithersburg, Maryland. However, several individuals participated in both workshops, and draft reports from two of the PEGI working groups were available for discussion. In fact, these draft reports served as a starting point for the Gaithersburg workshop.

In its 1993 report to the National Research Council titled *Wind and the Built Environment - U.S. Needs in Wind Engineering and Hazard Mitigation,* the Panel on the Assessment of Wind Engineering Issues in the United States stated the following:

> "The Panel on the Assessment of Wind Engineering Issues in the United States concludes that the key to implementing these recommendations is the immediate establishment of a National Wind Science and Engineering Program. This national program, enacted by the U.S. Congress and backed by a sustained budgetary commitment, would revitalize wind-hazard research. *To minimize human suffering and property losses in the future, it is important to encourage the professional community to proceed with research, to develop effective technology transfer methodologies, and to implement existing technologies.* This program must be established now to reach the goals set forth herewith with a minimum funding level of $20 million per year for the first five years."

The report goes on to identify key needs and specific recommendations for research and the implementation of research findings in the following areas:

Wind Hazards and Related Issues
Nature of the Wind
Wind Engineering
Mitigation, Preparedness, Response, and Recovery
Education and Technology Transfer
Cooperative Efforts

The NIST/NOAA Workshop on Environmental Technologies, held at NIST on April 26, 1993, identified severe storms and wind engineering as critical technical issues in environmental hazard mitigation. Also identified as critical technical issues were measurement standards and advanced sensor technology.

Another workshop that provided useful information and terms of reference is the Workshop on Wind Characterization, sponsored by the Office of the Federal Coordinator for Meteorology (OFCM) and held at Rockville, Maryland, on October 29-30, 1992. An important product resulting from this workshop is the draft standard titled "OFCM Standard Method for Characterizing Surface Wind."

Two bills, S. 4 and H.R. 6039, were introduced in the 102nd Congress that would have established a wind engineering research program within the National Institute of Standards and Technology with interagency coordination among NIST, NOAA, NSF, FAA, and other appropriate agencies. Funding for the program was to ramp up to a maximum of $5 million per year. The proposed program became a part of the National Competitiveness Act (H.R. 820) in the 103rd Congress. Although no action was taken to create and fund a national wind engineering research program, the proposed legislation does reflect a growing concern for the high level of wind damage experienced each year in the United States.

3.0 WORKSHOP ORGANIZATION AND OBJECTIVE

The motivation for this workshop was to bring together representatives of institutions currently engaged in wind engineering research to determine how best to proceed, given the fact that the current low level of funding is likely to obtain over the foreseeable future. Specifically, the objective was to identify ongoing research activities and existing research facilities at universities and at Federal agencies that could become more effective through meaningful university/agency collaboration. To this end, the following issues were identified and served as a workshop focus:

- What is being done now in wind engineering research?
- What are the critical issues in wind engineering and how can we best address them?
- How can we increase collaboration among the universities and the Federal agencies?
- Approximately, what is the current level of funding in wind engineering research?
- What level of effort is needed and what will it cost?
- Where do we go from here; is there a need for another workshop?

To seek answers to these questions, the first morning of the workshop was devoted to the presentation of program overviews by the workshop participants, and selected overviews are contained in this workshop proceedings. The remainder of the workshop was devoted to working group deliberations and the presentation at a final plenary session of the findings and recommendations developed by the working groups.

4.0 SUMMARY OF FINDINGS AND RECOMMENDATIONS

Workshop findings and recommendations are presented in each of the respective working group reports. Key findings and recommendations can be summarized as follows:

- Current funding for wind engineering research in the United States is approximately $750 thousand per year.

- A funding level of $25 million to $30 million per year for a period of 5 years is needed to meet the most critical research needs and to upgrade existing research facilities.

- A one-time expenditure of $25 million is needed for construction of new testing facilities.
- There is a need to establish extreme wind climatologies for hurricanes, tornadoes and other extreme wind events based on measurements.
- Improved wind sensors capable of surviving extreme wind events are needed.
- An interdisciplinary effort is needed to produce wind-field analyses in severe storms and to model damage location and magnitude on a near real-time basis for input to emergency response and recovery efforts, and for use in mitigation analysis.
- There is a need to develop and apply a methodology for re-calibrating the Fujita F-Scale speed/damage relationship.
- There is a need to develop measurement standards, archival standards, and quality assurance procedures for wind-tunnel and full-scale measurements.
- Many of the performance tests for building materials today are inadequate because they do not represent real or equivalent conditions found in prototype structures exposed to extreme winds. A four-step approach is recommended:
  - (1) Full-scale measurements in the natural wind
  - (2) Full-scale measurements in simulated extreme winds
  - (3) Wind tunnel simulations
  - (4) Develop equivalent, simplified static, dynamic, or cyclic tests
- Design guides are needed for a variety of situations involving high winds. Cost-benefit and reliability measures should be factored into these guides.
- Research should develop methodologies to define the degree and extent of retrofit that would be beneficial to the building owner and to society. Expert systems show great promise for this task.
- The definition of "loss" must be established by various segments of society to establish the current reliability for various systems. Subsequently, "society" must decide whether to continue to accept the current reliabilities, or to establish new "target" reliabilities.
- There is a need to establish design criteria which reflect system reliability as opposed to component reliability.
- There is a need to develop electronic formats for codes with knowledge-based features.

5.0 WORKING GROUP REPORTS

WORKING GROUP 1

METEOROLOGY, EXTREME-WIND CLIMATOLOGY, INSTRUMENTATION, POST-DISASTER ASSESSMENTS, DATABASES

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Findings and recommendations developed by working group 4 at the recent workshop "Reducing Losses in Wind Disasters: The Role of Government and Private Industry" were discussed. Strategies for new types of wind measurement technology, wind measurements and archival strategies were considered, and priorities for future research were established. One of the high priority issues is the identification of extreme wind characteristics and establishment of an extreme wind climatology based on actual measurements rather than on inferences from damage surveys. The modernization of the National Weather Service is providing improved real-time observing capabilities on severe wind storms, especially on the mesoscale. There must be coordinated interdisciplinary research to improve our understanding of severe wind phenomena and their impact on the built environment. Feedback from this research will improve severe storm warning techniques and guidance products. Concomitantly, there must be research on improved methods and technology for warning dissemination. These coupled research activities are all crucial to achieving our goal of improved damage mitigation strategies. Research should be designed to take advantage of the tremendous improvement of measurement capabilities. Additional high priority research objectives include field measurements of the horizontal distribution of the wind, fine-scale turbulent structure of the wind, the vertical profile of the horizontal component of the wind in the lowest 300 m, the response of the wind to changes in terrain roughness, and the relationship of extreme winds to convective scale features observed in radar displays.

Special opportunities exist for the collection of comprehensive data sets through interdisciplinary field programs in conjunction with NOAA research laboratory studies of tornadoes (e.g. VORTEX) and of hurricanes (AOML hurricane field program). VORTEX has resulted in the development of mobile ground and air-based observing systems, including portable Doppler radars and instrumented automobiles for the measurement of extreme winds in tornadoes. The NOAA hurricane field program includes a component to combine airborne and Nexrad Doppler radar measurements with surface observations to improve radar and satellite wind estimation algorithms and to study the 3-D wind distribution. These field programs are highly cost effective since many of the facilities involved are used year-round to support a wide variety of experiments.

An electronic archive of preliminary analyses and data sets should be made available to assist post-storm damage surveys and to serve as a clearing house for windstorm research. Sites should be established to provide access to comprehensive data sets, including a site for hurricane events and a site for tornado and severe thunderstorm events. This effort will require metadata to identify measurement limitations. A data publishing standard addressing metadata, quality control, availability, and security is required. A data rescue effort by transfer to optical media is critical to save important historical data sets that are currently archived on magnetic tape. Higher priority should be given to online and timely access of quality-checked wind data for severe storm events and to developing climatological statistics at the National Climatic Data Center.

Additional objectives include an extreme wind modeling component. As operational wind analysis methods improve, it will soon be possible to model infrastructure damage as a function of quantities determined from the wind field and storm track. As more wind storm data sets become available, it is important to construct damage assessment models to assist decision making for emergency managers and to support recovery efforts immediately following the event. Although much progress has been made in modeling mesoscale convective storms and hurricane tracks, mesoscale modeling of hurricane wind fields and tornado genesis is just beginning. These efforts will take several years to bear fruit and will need to be driven by observations. Meteorological models need to be configured for extreme wind risk assessment for engineering applications; new models should be identified for potential application to risk assessment. An integrated, collaborative effort is needed with participation by meteorologists and wind engineers.

In order to achieve these objectives, sensor performance must be improved for survivability, and recording capability must be made a standard feature. These needs are covered by the draft standard: "OFCM Standard Method for Characterizing Surface Wind" prepared by the Office of the Federal Coordinator for Meteorology (OFCM) workshop on surface wind standards held in Rockville, Maryland, in October, 1992. We endorse this draft standard and recommend its submission to national and international standards organizations. A comprehensive archiving capability is required for terminal and Nexrad Doppler radars, Low-level Wind Shear Alert System (LLWAS), Automated Surface Observing System (ASOS), Automated Weather Observing System (AWOS), and Coastal Marine Automated Network (CMAN) observing platforms that will allow threshold-controlled recording at high resolution. As a cost effective starting point, the National Data Buoy Center should consider equipping CMAN stations with hi-resolution, threshold-activated recording capability. Consideration should be given to increasing the maximum design wind of ASOS wind sensors from 56 to 90 m/s (125 to 200 mph). All critical facilities (refineries, nuclear facilities, hazardous waste storage sites) should be instrumented with rugged sensors for extreme wind risk assessment. New wind sensor designs will require careful attention to details such as sensor height, uninterruptible power, high resolution or peak event recording, mounting for survival, and mast design to survive missile impact. A study of possible approaches to the deployment or siting of anemometers in severe wind storms should be considered. Possible approaches include rapid deployment of sensors, fixed networks of locally deployed sensors, and fixed permanent sensors. Utility companies and other weather sensitive groups may be interested in participating in such efforts.

As more information on extreme winds becomes available it is important to re-evaluate and update existing extreme wind climate statistics. In this respect, both area and point probabilities of recurrence should be considered. It is also important to correlate damage surveys with available extreme wind measurements. The Fujita (F) scale damage survey techniques currently in use require calibration in terms of available observed and remotely-sensed wind speeds, as well as through engineering studies of construction practices and vegetation characteristics. The variability of F-scale wind estimates makes such estimates marginal for use in damage surveys. Calibration of the F-scale is needed from an engineering and meteorological viewpoint. A methodology and procedure for assessing F-scale values is needed since F-scale climatologies and data sets exist for tornadoes, microbursts and hurricanes. The official climatological record should indicate how the F-scale assessment was made, as well as the maximum wind speeds and the methods used to obtain them. Volunteers from the engineering and meteorological communities should be enlisted to participate in post-storm surveys. Warning and coordination meteorologists and Science Operations Officers of the modernized weather service will require training to apply new techniques for documenting damage sites. Conceptual models for damage to various types of structures and local construction vernacular as a function of wind speed should be developed to support this effort.

Working Group 1 estimates the funding level required to adequately support the research efforts outlined herein at $3 million per year.

A summary of research topics from the working group on meteorology follows:

- Establish an extreme wind climatology for hurricanes, tornadoes and other extreme wind events based on measurements.

- Establish coordinated interdisciplinary research to improve understanding of severe wind phenomena and their impact on the built environment.

- Measure wind in the lowest 300 m of the atmosphere in extreme events including distribution of wind speeds over area and its temporal variability, vertical profiles of mean velocity and turbulence structure at fine scales, response of the wind to changes in terrain roughness, and relation of extreme winds to convective scale features observed in radar displays.

- Develop improved wind sensors capable of surviving extreme wind events.

- Improve methods and technology for warning dissemination.

- Establish archives for wind storm research data, including data quality evaluation, data publishing standards, and rescue efforts for data currently archived on aging magnetic tape.

- Improve mesoscale numerical modeling of extreme wind events using measured data sets for validation.

- Establish an interdisciplinary effort to produce wind-field analyses in severe storms and to model damage location and magnitude on a near real-time basis for input to emergency response and recovery efforts, and for use in mitigation analysis.

- Upgrade existing measurement systems such as the Coastal Marine Automated Network platforms and the Automated Surface Observing System to include rugged sensors designed specifically for extreme event measurements.

- Archive extreme wind events from currently available instruments such as the Nexrad Doppler radars, Automated Surface Observing System, Low-Level Wind Shear Alert System, and other sources. Data should be assessed for quality and should be available on a timely basis.

- Evaluate and update existing extreme wind statistics.

- Develop and apply a methodology for re-calibrating the Fujita F-Scale speed/damage relationship.

WORKING GROUP 2

WIND TUNNEL MODELING, FULL-SCALE STUDIES, PRESSURE AND FORCE COEFFICIENTS, DATABASES

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In order to lay the groundwork for subsequent discussions of specific research needs, Working Group 2 began its deliberations by identifying a number of focus areas. In addition, most research focus areas will need to address various structures differently, depending on meteorological and exposure conditions. Consequently, Working Group 2 produced listings of categories of structures, types of wind events, and ranges of exposures which need to be addressed.

There was a consensus within the Working Group that wind engineering research should focus on developing an understanding of the fundamentals which lie behind the empiricisms and tests commonly used to obtain design information. This focus on the fundamental understanding of phenomena is critical to the development of realistic experimental and analytical models and to prototype testing. Working Group 2 recommends that a focus of wind engineering research should be directed towards the application of fundamentals to develop creative design solutions to wind problems. In many instances, design alternatives may be developed which would significantly reduce the risk of wind damage.

A key focus area for research is the development of creative approaches to reproducing physical phenomena at model-scale and at full-scale. This will likely require the development of new facilities or the modification of existing facilities. Consequently, it is recommended that an initial task involve a review of existing public and private facilities, including DOD and NASA facilities which might be adapted to the simulations proposed. The modification of existing facilities or the construction of new facilities must be based on understanding and reproducing the important physical processes involved in the interaction of wind with structures. The physical processes which control the fluid-structure interaction may be different for various types of structures or components of structures. Thus, research is needed for a variety of structures including low-rise buildings, high-rise buildings, bridges, towers, stacks, transmission lines, offshore structures, and transport vehicles.

Destructive testing of prototype structures also was identified as a needed focus. The resistance of ordinary low-rise buildings to wind loads is poorly understood. Relatively little research has been directed towards improving the understanding of capacities of components, connections, and systems to resist realistic wind loads.

In addition, the characteristics of wind events are different depending on the type of event and the wind exposure or terrain surrounding the structure. Consequently, another focus area is research directed towards understanding the characteristics (climatology) of different types of storms including extratropical, hurricane, tornado, thunderstorm, microburst, and downburst events for a range of exposures which, depending on the event, might range from ice to complex terrain. These climatologies are needed in order to ensure that flow characteristics are better understood and important features of the flow are reproduced in physical and analytical models.

As researchers seek to characterize the full-scale phenomena through measurement programs, it is imperative that standards be developed and followed for both measurements and data storage. This requires the development of archival standards and quality standards for the data. Decisions must be made concerning the types of data to be collected simultaneously and a method of identifying the types of data (meteorological, pressure, loads, or response) that are collected. A group or agency must be identified to maintain the archive or archives.

SUMMARY OF RESEARCH NEEDS

Physical Modeling in Wind Tunnels

Identification of Wind Tunnel Facilities

- Types of wind tunnels
- Major U.S. facilities
- The need for new facilities

Improved Modeling of Wind and Wind Effects

- Develop simulations for extreme wind events
- Pressure models
- Fluctuating load models
  - Multi-point synchronous pressure models
  - High-frequency base balance models
  - Aeroelastic models
- Other types of models
- Development of new or improved instrumentation and data processing systems

Full-Scale Studies

Identify and Characterize Existing and Needed Full-Scale Research Facilities

Studies for Various Classes of Structures

- Low-rise structures
- High-rise structures
  - Buildings
  - Towers
  - Stacks

- Long-span structures
  - Bridges
  - Roofs
  - Transmission lines

Coordination With Companion Studies

- Wind-tunnel model studies
- Meteorological measurements
- Analytical studies
- Computational modeling studies

MOCK-UP INVESTIGATIONS

- Identify Existing and Needed Mock-up Testing Facilities
- Evaluate and Improve Common Mock-up Investigations
  - Curtain-wall assemblies
  - Roof coverings
  - Solar energy collectors
- Development of Advanced Mock-up Testing Technology

DATABASE DEVELOPMENT OF PRESSURE, FORCE AND MOMENT COEFFICIENTS (Model and Full-Scale Investigations)

- Low-rise Building Variables
  - Building plan
  - Roof type
  - Adjacent buildings
- High-rise Structure Variables
  - Cross-section geometry
  - Height
  - Porosity (unclad buildings, lattice towers, etc.)
  - Natural frequencies
  - Damping
  - Adjacent buildings
- Long-span Structure Variables
  - Bridge deck geometry
  - Roof type
  - Natural frequencies
  - Damping
  - Topography and adjacent structures
- General Variables
  - Types of storm events and wind characteristics
  - Types of exposures (uniformly rough flat terrain, urban settings, complex terrain, etc.)

ARCHIVAL CENTER

There is a need for a central archive dedicated to wind-tunnel and full-scale test data as opposed to climatological data. Such an archive would serve the wind engineering research community as well as providing access to certain databases for use with expert systems.

FINDINGS AND RECOMMENDATIONS

Areas of Highest Priority:

1. Reproduction of Intense Negative Pressures on Wind-Tunnel Models

2. Proper Prototype/Mock-up Testing
   Facilities, instrumentation, prototype instrumentation

3. Wind Characteristics of Hurricanes, Tornadoes and Thunderstorms
   Can we apply conventional pressure coefficients?

4. Influence of Turbulence

5. Comparisons Between Results
   Laboratory to laboratory; laboratory to full scale; numerical to full scale and to laboratory

6. Complex Terrain Simulations and Sites
   Model and full scale

7. Full-Scale Databases
   Meteorology/pressures/loads

Areas of Lower Priority:

1. Wind-Tunnel Databases
   Standards needed prior to development of databases

2. Reynolds Number Effects for Small Features and Curved Surfaces

3. Influence of Architectural Features on Flow and Loads (and vice versa)

CURRENT ANNUAL EXPENDITURES

Areas of Highest Priority	Approx.	$700K
Areas of Lower Priority	Approx.	60K

NEEDED ANNUAL EXPENDITURES (For full programs)

Areas of Highest Priority		$8M
Areas of Lower Priority		2M
Upgrading of Facilities/Equipment		3M
Operation of New Facilities		3M
	TOTAL	$16M

NEW ONE-TIME EXPENDITURES

Major New Testing Facilities	$25M

WORKING GROUP 3

MATERIALS AND COMPONENT TESTING, POST-DISASTER ASSESSMENTS

Joseph E. Minor, Chair
James R. McDonald, Rapporteur
William Freeborne
Clifford Oliver
Ben Sill
Thomas L. Smith
Charles W.C. Yancey

Working Group 3 elected to alter the scope of the discussion topic, which was the group's prerogative. The scope of the discussions was directed to new construction and retrofit of existing structures. Although the general approach of research leading to technology transfer and implementation is essentially the same for new construction and for retrofit, the subjects are different, but some overlap is possible.

Figure 1 shows an outline of the process defined by the working group. Research and design strategies constitute research efforts in themselves. The group felt it important that a distinction be made between research efforts that could be accomplished in a short period of time (say one year) and those that would require a longer time period (three years or more). The short-term projects are identified in Figure 1 as ready for technology transfer (RFTT) and long-term research (LTR). Once the research is accomplished, it is ready for technology transfer and implementation. By identifying those research elements that can be accomplished in a short time period (RFTT), clear accomplishments can be demonstrated early in the program.

RESEARCH AND DESIGN STRATEGIES FOR NEW CONSTRUCTION

Examples are listed in Table 1. Each item is described briefly.

- Innovative Structural Systems - New materials and technologies should be examined to arrive at structural systems that will perform better than current ones in high winds and that will prove cost effective.

- Development of Appropriate Test Methods - Many of the performance tests for building materials today are inadequate because they do not represent real or equivalent conditions found in the prototype structure. A four-step approach is recommended:

  (1) Full-scale measurements in the natural wind
  (2) Full-scale measurements in simulated extreme winds
  (3) Wind tunnel simulations
  (4) Develop equivalent, simplified static, dynamic, or cyclic tests.

- Idiot-proof Construction - Develop processes and materials that are impossible to install in inappropriate applications or in an incorrect manner.

- Redundancy (fool-proof construction) - Provide for redundant load paths so that if a component in a load path fails, alternative paths are available to transfer loads to the foundation.

- Land Use - Land use management has been shown to be an effective tool in flood damage mitigation. The concept should be explored for application to wind hazard mitigation.

- Design Guides - Design guides are needed for a variety of situations involving high winds. Although development of design guides could be considered as technology transfer, cost-benefit and reliability measures should be factored into the guides.

- Continuous Load Transfer Paths - Construction details must be developed and evaluated that will provide appropriate continuous load paths.

- Wetproofing for Rain Intrusion - This concept accepts the possibility of rain intrusion, but utilizes materials that are resistant to wetting.

- Emergency Measures as Storm Approaches - Identify actions that can be taken by homeowners to improve wind resistance and survivability as the storm approaches (e.g. installation of shutters).

- New Materials - Developing new materials, especially for protection of the building envelope (e.g. roofing systems, cladding, windows, doors, etc.).

- Education - Research ways to educate designers, builders, and the public; convince them of the importance and benefits of damage mitigation.

RESEARCH & DESIGN STRATEGIES FOR RETROFIT OF EXISTING CONSTRUCTION

Retrofit is the key to long-term damage mitigation because there are so many existing buildings and facilities that are susceptible to wind damage. Table 2 summarizes strategies for retrofit. Each item is described briefly.

- Improved Protection of Envelope - Develop test methods and evaluate schemes for protecting the building envelope. Some strategies are best applied during routine maintenance; other strategies will be applied during deliberate upgrade.

- Load Path Continuity - Weaknesses in the load path must be identified and measures developed to overcome these weaknesses.

- Non-Destructive Test Methods - Methods are needed by which to evaluate the in situ strength of components and connections.

- Trigger Mechanisms - Identify factors (triggers) that suggest the need for retrofit. This involves risk assessment and planned maintenance.

- New Materials - Identify and evaluate new materials as replacements for existing materials to achieve better wind resistance.

- Innovative (screw ball) Techniques and Devices - Analyze and evaluate such techniques and devices for improving wind resistance. All kinds of ideas and schemes are being proposed. A formal procedure for evaluating their effectiveness is needed.

- Design Guides and Standards - These guides should come from research findings to ensure that retrofit techniques are effective.

- Sacrificial Components - This concept recognizes, for example, that asphalt shingles will be blown away in high winds and provides a water-proof membrane underneath to keep out rain.

- Education - Owners must be aware of the benefits of retrofit. Designers and builders must have the knowledge required to carry out the processes.

- Degree/Extent of Retrofit - Research should develop methodologies to define the degree and extent of retrofit to be beneficial to the owner and to society. Expert systems show great promise for this task.

RESEARCH AND TECHNOLOGY TRANSFER

Time did not permit a full exploration of specific research topics. The working group was only able to identify a few examples of specific projects. Table 3 summarizes examples of short-term (RFTT) and long-term (LTR) projects. These projects are applicable to both new construction and retrofit.

READY FOR TECHNOLOGY TRANSFER (RFTT)

Four examples are listed in Table 3. Each item is described briefly.

- Gravel Blow-Off - Kind and Wardlaw conducted research to quantify gravel blow-off from single-ply membrane roofs. Relatively little research effort is needed to put the results of Kind and Wardlaw into a form that can be used by roofing design consultants.

- Wind Pressures on Metal Edge Flashing - Wind tunnel tests, full-scale and numerical modeling of metal edge flashing and copings are currently being conducted. Results in the form of design guides can be provided in a relatively short time.

- Shutters - The use of shutters to protect glazed openings is growing in popularity. Test methods for wind-borne debris impacts are being developed and implemented.

- HVAC Rooftop Anchorage - Techniques for rooftop anchorage of HVAC equipment are generally inadequate. New guidelines and techniques could be developed in a relatively short time frame, based on either full-scale testing or wind tunnel studies.

LONG-TERM RESEARCH (LTR)

Examples are listed in Table 3. Each item is described briefly.

- Architectural Features - To reduce wind pressures and to mitigate potential damage, architectural features need to be explored in a systematic manner, cataloged and recommended. The concepts could be as simple as parapet walls and as complicated as special roof shapes.

- Develop and Validate Test Methods - Various test methods are needed for evaluating the performance of roofing and wall cladding materials. The test methods need to be developed, validated and implemented.

- o Instrumentation for Non-Destructive Testing - The details of connections and anchorage are often inaccessible in an existing building. New instrumentation is needed to locate anchor bolts, reinforcing steel, and other features of the wind resisting system.

The above research projects are merely examples of the type of research needed for both new construction and retrofit. Research and design strategies will identify many more such projects. The working group did not attempt to estimate costs of these individual projects or to identify agencies to perform the work. Research programs funded at a level of from $3 million to $5 million per year are needed to address the problems identified herein on a long-term basis.

POST-DISASTER DAMAGE ASSESSMENT

Four members of the working group had addressed the post-disaster damage assessment issue at the Private Enterprise-Government Interactions (PEGI) Conference held in Golden, Colorado, June 1994. Working Group 3 endorses the findings and recommendations developed at the PEGI Conference and they are summarized in Table 4.

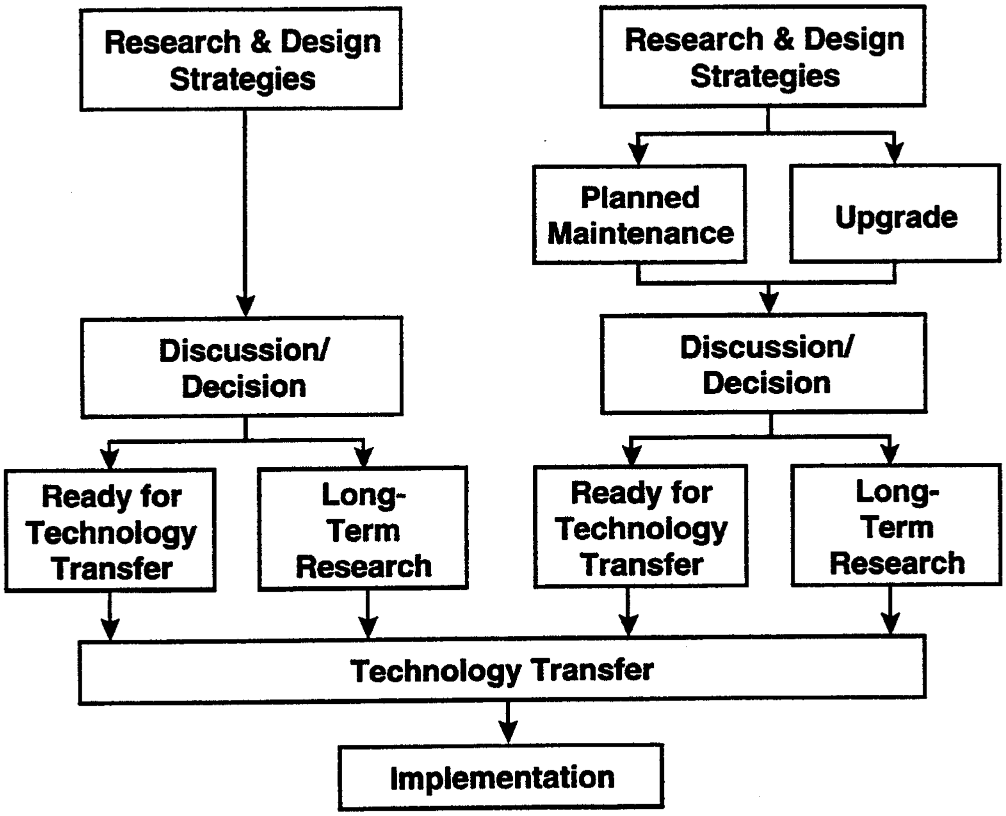

Figure 1. Research and Design Strategies

Table 1. Research and Design Strategies for New Construction.

- Innovative Structural Systems
- Development of Appropriate Test Methods
- Hurricane-Resistant Approach
- Idiot-Proof Construction
- Redundancy (foolproof construction)
- Land Use
- Design Guides
- Continuous Load Transfer Paths
- Wetproofing for Rain Intrusion
- Emergency Measures as Storm Approaches
- New Materials
- Education

Table 2. Research and Design Strategies for Retrofit of Existing Construction

- Improved Protection of Envelope
- Load Path Continuity
- Non-Destructive Test Methods
- Trigger Mechanism (Risk-Based, Planned Maintenance)
- New Materials
- Innovative (screw ball) Techniques and Devices
- Design Guides and Standards
- Sacrificial Components
- Education
- Degree/Extent of Retrofit

Table 3. Research and Technology Transfer

Items Ready for Technology Transfer (RFTT)

- Gravel Blow-Off
- Wind Pressures on Metal Edge Flashing
- Shutters
- HVAC Rooftop Anchorage

Items for Long-Term Research (LTR)

- Architectural Features
- Develop and Validate Test Methods
- Instrumentation for Non-Destructive Testing (NDT)

Table 4. Post-Disaster Damage Assessment

- Stand-by Damage Assessment Teams
- Requires Consistent Funding
- Government, Private Sector, University Participation
- Central Repository for Field Data
- Improve Consistency of Assessments/Reports
- Endorse Findings and Recommendations of PEGI Conference, Golden, Colorado, June 23-24, 1994
- This effort will require significant dollars.

WORKING GROUP 4

STRUCTURAL MODELING AND ANALYSIS, RELIABILITY, RISK-CONSISTENT DESIGN, COST-BENEFIT STUDIES

Norris Stubbs, Chair
Gregory Chiu, Rapporteur
Marvin E. Criswell
John Gross
Ahsan Kareem
Dale C. Perry

Defining the critical issues--the current state of knowledge and subsequent research needs--was the initial basis of discussion. The Working Group's deliberations eventually centered around the ideas of defining acceptable losses, and designing and implementing the tools required to attain those goals. The research tasks required to create the tools were delineated and are described below.

IDENTIFICATION OF RESEARCH TASKS

Task 1. The definition of "loss" must be based on input from various segments of society to establish the current reliability for various systems (e.g., structural loss, lifeline loss, socio-economic loss, etc.). Subsequently, "society" must decide whether to continue to accept the current reliabilities, or to establish new "target" reliabilities; should new reliabilities be desired, they will be defined by the respective disciplines which require them.

Examples of systems for which target reliabilities are required:

- o Serviceability failure criteria
- o Life-safety failure criteria
- o Maintainability
- o Serviceability: Including human comfort, HVAC, cracking of partitions, etc.

Quantify serviceability depending upon definition and let definition be set by various people.

Importance Level: *High*

Task 2. More attention must be given to initial design and conceptual design of systems to reduce the effects of wind-hazard.

Once an initial design has been selected, a risk-consistent and optimal design can be developed for the system of interest.

Importance Level: *High*

Task 3. Current reliability of the existing building inventory must be evaluated; a necessary step before new target reliabilities can be defined or mitigation schemes can be developed and implemented for the current inventory. (We have to establish where we are before we can decide where to go).

3.1 Documentation of the life-cycle costs of existing inventory.

3.2 What is the reliability of current building code requirements?
  3.2.1 Prescriptive requirements
  3.2.2 Performance requirements

Importance Level: *High*

Task 4. Load paths (both engineered and non-engineered structures). Issue: Do we even understand how load paths work to begin with?

Specific items regarding connections were identified as follows:

- Are current connection criteria satisfactory; are the connections resulting from code requirements too brittle; and

- Low-cycle fatigue (houses "breathing" in hurricane events).

Importance Level: *Medium*

Task 5. Establish design criteria (basis) to reflect system reliability instead of component reliability.

Importance Level: *High*

Task 6. Should ductility be considered explicitly in hurricane-resistant design for all structures; particularly low-rise structures?

Importance Level: *Medium*

Task 7.

A. Study the impact of the failure of non-structural components on the performance of the system (progressive collapse). This would include consideration of different modes of protection and failure; e.g., would it be better to account for the breaking of a window (internal pressure design criteria) or to make an impenetrable window.

Importance Level: *High*

B. Study the impact of the quality of design of the building envelope (independent of the issues related to the classical structural system) on damage to the structure and damage to contents. Evaluate the relative impact of increasing the resistance of the envelope.

Importance Level: *High*

Task 8. Localized failure modes (differentiate from Task 7, roofing-type problems, or other failures resulting from inattention to detail and perhaps leading to progressive collapse).

Importance Level: *High*

Task 9. Effect of deterioration, environmental degradation and fatigue on component and system reliability.

Importance Level: *High*

Task 10. Study how hazardous processes (the meteorological event) lead to hazardous events (the negative results of the meteorological event).

Some hazardous events which result from the hazardous process:

- Wind speeds
- Water-related events: Storm surge, wave action, flooding (run-off)
- Air-borne missiles
- Load combinations
- Space-time distribution of wind speeds and resulting aerodynamic loads on structures in isolated and in cluster configurations located in different terrain conditions.

Importance Level: *High*

Task 11.

A. Developing improved reliability analysis techniques and performing experimental validation.

Importance Level: *High*

B. Evaluating code requirements in light of the improved analysis techniques obtained from Task 11A.

Importance Level: *High*

C. Validation of the variation between a "perfect code-compliant structure" and the real world of "as-built" structures.

Importance Level: *High*

Task 12. Codes and design provisions in electronic format with knowledge-based features. Electronic aids for code checks, etc.

- o Expert systems
- o Knowledge-based systems
- o Decision support systems
- o Electronically stored building codes

Importance Level: *Medium*

UNIVERSITIES AND OTHER RESEARCH CENTERS CURRENTLY INVOLVED IN RELIABILITY AND LOSS ESTIMATION

The Johns Hopkins University
Texas Tech University
The University of Notre Dame
University of Washington
University of Missouri
Colorado State University
Texas A & M University
University of Michigan
Stanford University
Clemson University
NIST
USDA/FPL (Forest Products Laboratory)

ESTIMATED COSTS

Working Group 4 estimated that an approximate cost to study all of the tasks listed herein would range between $4-6 million per year; reasonable results would require a minimum of five years of funding.

Task 1. Design Target Reliabilities ($500,000)

Tasks 3, 6, 8, 9. Performance of Existing Inventory ($1 million)

Tasks 2, 4, 5. Incorporation of New Design and Mitigation Philosophies ($500,000)

Task 7. Systems Reliability ($1 million)

Task 10. Hazard Modeling ($1 million)

Tasks 11, 12. Resistance Modeling ($1 million)

All projects should address the issue of technology transfer. The expected time line is 5-7 years from the formulation of a research topic to technology transfer; some projects will take longer, some will take less time.

DISTRIBUTION MECHANISMS

A distribution methodology is required that has the ability to:

- Issue contracts efficiently
- Monitor progress
- Provide technical management capabilities
- Avoid conflict of interest
- Facilitate heightened communication between projects
- Be impartial and objective
- Establish oversight committee

ADDITIONAL ISSUES

1. Given the large differences in pressures (particularly for low-rise buildings) for exposures B and C and the uncertainties and/or errors made in assigning design exposure, should there be an intermediate BC design exposure? Of concern is the need to provide uniform reliability.

2. Need studies to identify common structural weak links in common types of construction, along with ways to best correct these weaknesses.

3. Address/resolve questions (for midwest, southwest, southeast U.S., mainly) of when and how to design for survival of what size/magnitude of tornado--and for what class/occupancy of structures?

4. Risk-consistent design concern. For manufactured homes--what is the design reliability and the in-place reliability of tiedown devices and foundation systems?

5. What effect do inspection, supervision, quality control, code enforcement, construction practices, etc. have in determining the reliability actually provided?

6. Technology transfer--how best for the usual designer to understand and use "state-of-the-art" wind engineering knowledge and the general public to know/appreciate the general issues and expected performance of structures in extreme winds?

7. Formulation of design codes which adequately balance the following:

   Adequate accuracy and recognition of important parameters.
   Simplicity and utility with reasonable effort on the part of the designer.

8. There are many issues regarding common "structures" other than occupied building structures--not so much life safety issues, but issues that are important for societal services/operations.

6.0 RESEARCH INSTITUTION OVERVIEWS

CLEMSON UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING

CURRENT RESEARCH AREAS

Wind Loads on Structures

A project to mitigate losses from natural hazards - Task 1 of multitask project funded by FEMA, the State of North Carolina and Clemson University.

Research to improve the simulation of extreme suction loads on roofs of low-rise buildings - cooperative work with Virginia Polytechnic Institute and funded by the National Science Foundation.

Research on wind loads for buildings located in the coastal zone where the wind field is in transition - funded by the South Carolina Sea Grant Consortium.

Investigation of the technical feasibility for constructing a National High-Wind Impact Laboratory "Wall of Wind" (described herein) - funded by the Insurance Institute for Property Loss Reduction and State Farm Insurance.

Investigation of wind loads for buildings located on escarpments - cooperative research with Texas A&M University and funded by the National Science Foundation.

Structural Resistance to Wind Loads and Wind Effects

Withdrawal capacity of various roof sheathing fasteners in plywood and OSB - Task 2 of FEMA related project partially supported by APA and ISANTA.

Wind uplift capacity of standing-seam metal roofs - supported by Task 2 of FEMA related project and MBMA.

Structural stability of low-rise timber and masonry structures, including design, development and testing of retrofitting alternatives - Task 3 of FEMA related project.

Debris impact loading of low-rise structures, including characterization of impact loads - supported by Task 3 of FEMA related project.

Wind-Induced Damage and Loss Characterization

Evaluation of economic losses associated with the damage of residential buildings, including the correlation of losses with wind speeds - supported by the South Carolina Sea Grant Consortium in cooperation with insurance companies.

Damage investigations after Hurricanes Hugo and Andrew - supported by the National Science Foundation.

RESEARCH FACILITIES

Large boundary-layer wind tunnel

Building Research Establishment Realtime Wind Uniform Load Follower (BRERWULF) with dynamic load capacity to 180 psf

2.59 x 1.37 m (8.5 x 4.5 ft) horizontal chamber, 7.01 x 3.66 m (23 x 12 ft) horizontal chamber, and 3.66 x 3.66 m (12 x 12 ft) vertical chamber for BRERWULF testing

1:20 scale functional model of "Wall of Wind" test facility

Universal Testing Machines - Structural Engineering Laboratory

PERSONNEL

S. Amirkhanian	Materials and Roofing
R. Brown	Masonry
T. Reinhold	Wind Loads, Wind Structure, Structural Resistance, Retrofitting
D. Rosowski	Reliability, Structural Resistance
S. Schiff	Structural Resistance, BRERWULF
B. Sill	Wind Loads, Wind Structure, Damage Investigations
P. Sparks	Wind Loads, Wind Structure, Loss Evaluation

FUTURE RESEARCH THRUSTS

Wind loads on various building shapes in a wide variety of exposures
The influence of surrounding structures on wind loads
Influence of architectural features on wind loads
Influence of wind characteristics on wind loads
Methods of reducing wind loads on low-rise buildings
Resistance of structural components and parts of the building envelope to dynamic loads
Resistance of connections to wind loads
In situ capacities of structures
Retrofitting schemes for buildings at risk

Reliability of components and systems subjected to extreme wind loads
Regional loss estimation

NATIONAL HIGH-WIND IMPACT LABORATORY "WALL OF WIND"

Background:

Following major windstorms, building community representatives, national experts in wind effects and local engineers have endeavored to put the damage into perspective and to identify the causes of the failures. In most instances this evaluation is hindered by the lack of reliable data on the winds encountered and the resistance or capacity of the structure or components to wind loads. Frequently, attempts are made to back-calculate wind speeds from the damage observations. Thus, the whole evaluation process becomes confused and it is very difficult to convince lay people, construction workers, builders, and in some cases even engineers, that relatively simple changes in materials and particularly in fastening methods could minimize the damage.

The uncertainty in wind speeds and the fact that most structures are not built exactly to code requirements or specifications provide designers and builders with an easy out if their building fails. An example of this is that although certain classes of buildings were devastated over wide areas in Hurricane Andrew, the building suppliers can still say that they have not found any buildings "designed and built to their standards" which have failed. This sort of evaluation has been used repeatedly over the years by various groups with vested interests in promoting their products. In many cases these defenses become a shield to protect the status quo and they confuse enough people to effectively prevent adoption of changes which would substantially improve the ability of buildings to withstand severe winds.

In order to combat this deep-rooted resistance to making necessary changes in design methods, construction details and construction techniques, a national facility is needed in which full-scale buildings can be subjected to the kinds of severe wind conditions that are known to occur in many regions of the United States. The proposed facility needs to be able to reconstruct the gust structure of strong winds at speeds high enough to encompass the range of expected strong winds for most of the country. Thus, the facility needs to be able to create rapidly varying wind speeds and to reflect the lateral and vertical correlation of the wind gusts. The wind field produced must be large enough to encompass a modestly sized structure which will allow the full three-dimensional nature of the flow separation around the structure to be reproduced. Only in this way will it be possible to recreate the intense negative pressures (suctions) which occur at three-dimensional corners and in other areas where flow separation occurs.

Concept for a National High-Wind Impact Laboratory:

Any idea of constructing a wind tunnel large enough to test a full-scale building is fraught with problems. Conventional wind tunnel designs would be inappropriate for a facility where large amounts of debris may be generated or even where small amounts of debris are generated and transported at high speeds. The failure of the turning vanes in the NASA Ames wind tunnel clearly demonstrated the potential problems. Also, the amount of power required for short periods of time to generate 90 m/s (200 mph) winds over an area the size of even a small building is extremely large. This power requirement is best met by internal combustion engines rather than by electric motors.

The most promising idea is to construct an array of turboprop aircraft engines with variable pitch blades mounted in a wall array. The along-wind gust structure can be generated by a combination of varying the speed of the engines and the pitch of the blades. If necessary, moving vanes can be added to generate fluctuations in the longitudinal, lateral and vertical wind directions. The open-jet wind tunnel at the Federal Highway Administration's Turner-Fairbank Highway Research Center uses moving vanes to create the desired turbulence characteristics for use in testing large-scale bridge models. There are technical issues which need to be addressed before any prototype facility plans are finalized. Research is needed to:

- Investigate how well the along-wind gusts translate into across-wind and vertical gusts.
- Evaluate the potential requirement for wall constraints and a roof constraint on the wind field generated by the engines to ensure integrity of the flow as it blows around the building.
- Determine requirements for the size of the engine array in relation to the size of the structure to be tested.

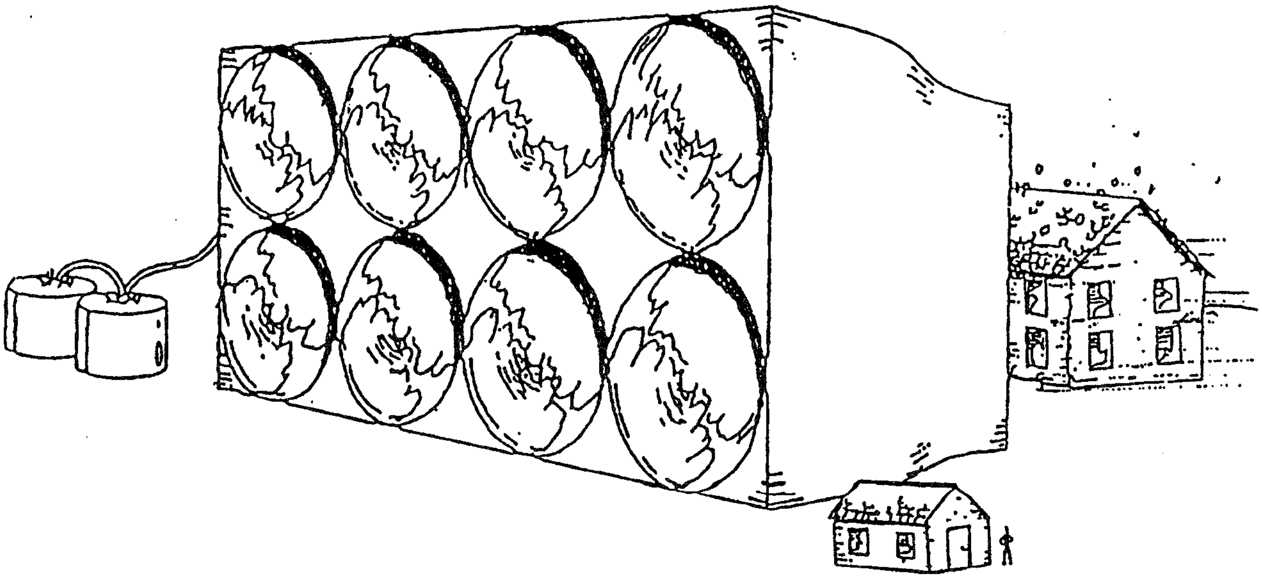

Figure 1. Concept of Wall of Wind

Performance Criteria for Facility:

- 90 m/s (200 mph) winds over an area sufficient to engulf a small single-family dwelling.
- Reproduction of various wind conditions - gust structure (longitudinal and lateral) and spatial correlation.
- Local and area-averaged loads along with flow over the surface.
- Prototype setup, testing and failure investigation areas.

Finalizing Aerodynamic Design:

- Construct 1/10th scale model facility.
- Evaluate potential requirements for wall and roof constraints on flow to ensure integrity of flow around building.
- Finalize design requirements for proper creation of gusts, including engine/propeller pitch control systems and possible moving vanes.
- Test 1/10th scale model building in model facility to compare pressures and local wind velocities with full-scale data and boundary-layer wind tunnel measurements.

The Role of NaHIL in Meeting National Goals:

- Support development of uniform codes by reducing uncertainty in loads and resistance.
- Graphic demonstration of advantages of proper construction will spur public awareness and demand for proper construction.
- Provide basis for assessment of existing test methods and development of new test methods or more realistic correlation of results from existing test methods with actual conditions.
- Consumer demand for better construction, coupled with economic incentives from insurance industry, will lead to repair and retrofit of existing buildings.

COLORADO STATE UNIVERSITY
ENGINEERING RESEARCH CENTER
FLUID MECHANICS AND WIND ENGINEERING PROGRAM

CURRENT RESEARCH AREAS

CSU/TTU Cooperative Program in Wind Engineering (CPWE)

Wind loads on small flat-roofed buildings
Internal pressures
Wind uplift on roofing pavers
Wind map for proposed ASCE 7-95
Numerical simulation of hurricanes
Numerical simulation of wind flow over small buildings

- Synthesis method for non-Gaussian pressure fluctuations

Wind Uplift on Roofing Shingles

- Wind-tunnel tests
- Wind load model
- Full-scale validation

Viscoelastic Damping in Building Design

High-Frequency Line-Integrated Concentrations

Resistance of Structures to Wind Loads

RESEARCH FACILITIES

Boundary-Layer Wind Tunnels

- Three large boundary-layer wind tunnels

CPP/ARMA Full-Scale Test House

- 10.67 x 7.01 x 4.57 m (35 x 23 x 15 ft) pitched roof house on turntable located in a high wind area near Fort Collins

Regional Atmospheric Modeling System (RAMS)

- Mesoscale numerical model of atmospheric processes

Structural Engineering Laboratory

- Focus on wood structures

PERSONNEL

B. Bienkiewicz	Wind loads, wind structure
J. Cermak	Wind loads, wind structure, pollutant dispersion
H. Cochran	Economic analysis, risk analysis
M. Criswell	Structural resistance
R. Meroney	Wind structure, pollutant dispersion
M. Nicholls	Numerical simulation
J. Peterka	Wind loads, wind structure, wind climatology
R. Pielke	Numerical simulation, atmospheric science

FUTURE RESEARCH THRUSTS

Boundary-Layer Wind Tunnel Tests

- Wind loads on small flat-roofed buildings
- Wind loads on small pitched-roofed buildings
- Wind loads on roofing systems
- Wind flow around buildings
- Fatigue analysis
- Reliability/uncertainty issues
- Non-boundary layer wind flows
- Other wind-tunnel modeling

Full-Scale Tests on the CPP/ARMA Test House

- Wind loads on steep roofing systems
- Wind loads on sloped-roof house frames/components
- Fatigue studies
- Full-scale wind structure

Numerical Simulation of Atmospheric Winds

- Hurricanes
- Downbursts
- Wind over complex terrain
- Wind flow over individual buildings
- Host 2nd International Conference on Computational Wind Engineering, 1996

Economic Analysis/Risk Analysis

- Costs and benefits of expenditures on mitigation

International Cooperation on Wind Mitigation Issues

Resistance of Structures to Wind Loads

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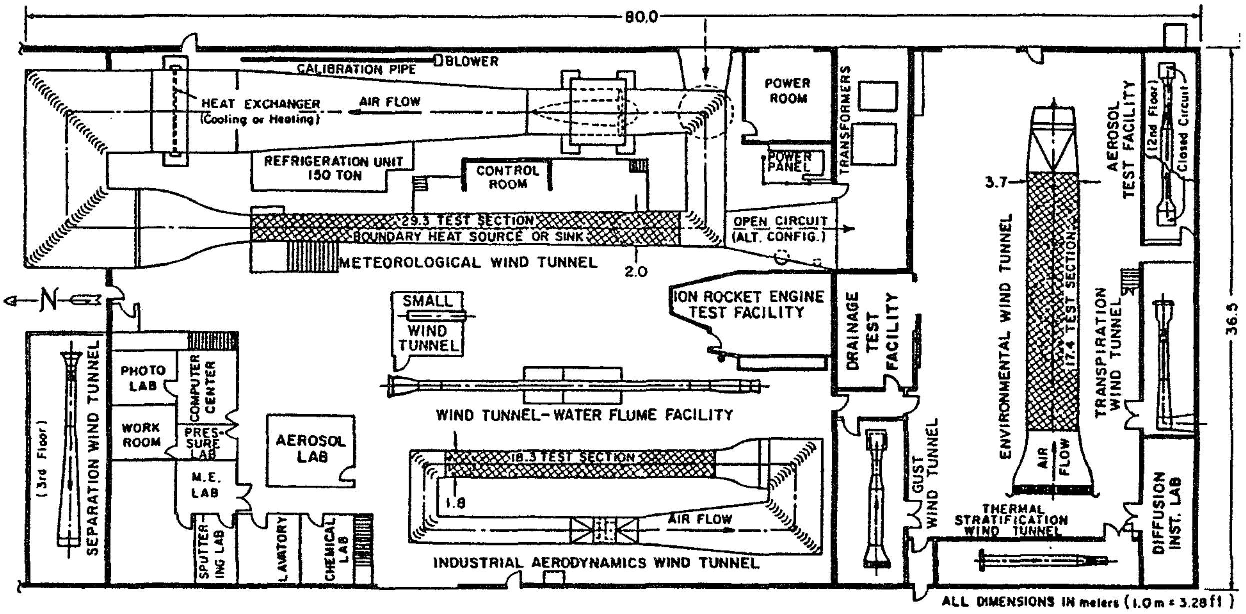
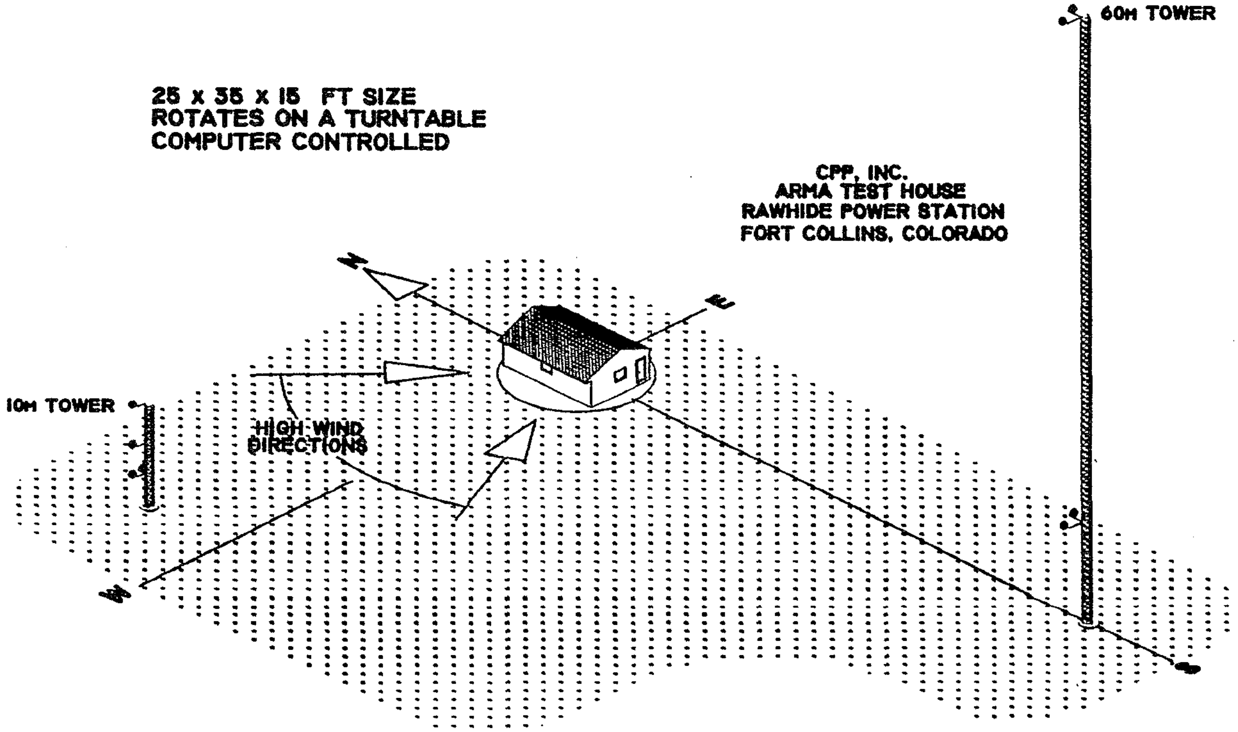


Figure 1. Fluid Dynamics and Diffusion Laboratory, Engineering Research Center, Colorado State University.



Note: 1 ft = 0.3048 m

Figure 2. CPP, Inc. ARMA Test House, Rawhide Power Station, Fort Collins, Colorado.

NOTRE DAME UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING & GEOLOGICAL SCIENCES
HESSERT CENTER FOR AEROSPACE RESEARCH

CURRENT RESEARCH TOPICS

- Reliability of Nonlinear Ocean Systems Subjected to Wind, Waves, and Currents
- Structural Motion and Control Devices
- Bridge Aerodynamics
- Computational Wind Engineering
- Gust Loading Factors (ASCE 7 - Minimum Design Loads for Buildings and Other Structures)
- Analysis of Nonstationary, Non-Gaussian Processes
- Collaborations with Civil, Mechanical, Chemical and Electrical Engineering

FACILITIES

- Wind Tunnels
- Unsteady Vertical Water Tunnel
- Flow Visualization Water Tunnel
- Shaking Table
- Reaction Frame with Actuators
- Workstation network
- Parallel supercomputer

FUTURE ACTIVITIES

- Modeling and analysis of nonstationary wind and associated load effects utilizing wavelets (e.g., thunderstorm winds, hurricane winds, squall lines)

- Modeling and simulation of non-Gaussian processes and fields (e.g., pressure fluctuations and near-surface turbulence)

- Gust loading factors; local and integral loads; fatigue

- Modeling and quantification of uncertainty in wind loading and resistance chain and its integration with long-term statistics to develop load and resistance factors (LRFD)

- Compilation and modeling of aerodynamic loads on high-rise buildings for inclusion in ASCE 7

- Modeling of large-scale turbulence using air injection system

- Numerical modeling of wind effects on structures

- Integral risk assessment of coastal facilities

HESSERT CENTER FOR AEROSPACE RESEARCH

The Hessert Center for Aerospace Research, a 3,250 m^2 (35,000 sq ft), state-of-the-art research building designed for conducting fundamental research in fluid mechanics, aerodynamics, and structural dynamics. The research laboratory houses numerous wind tunnels and specialized laboratory facilities. Table 1 is a list of the wind tunnels and specialized laboratories.

Table 1. Research Facilities in the Hessert Center for Aerospace Research

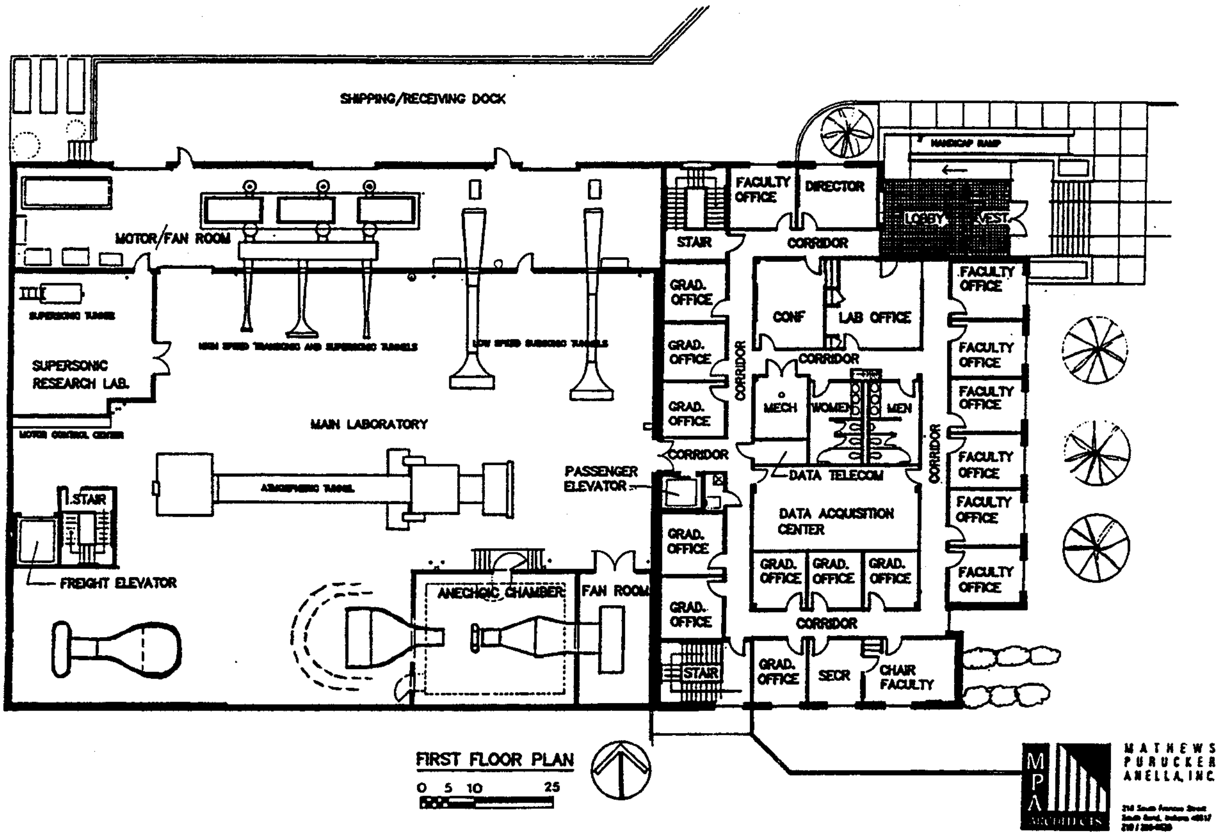
2 Low-speed Subsonic Wind Tunnels
1 Atmospheric Boundary Layer Tunnel
1 Eidetics Water Tunnel
1 Anechoic Wind Tunnel
2 Supersonic Wind Tunnels (continuous flow)
1 Transonic Wind Tunnel (continuous flow)
1 Blowdown Supersonic Tunnel
1 Structures Laboratory
1 Aero-optics Laboratory
1 Particle Dynamics Laboratory
1 Image Processing Laboratory

ATMOSPHERIC BOUNDARY LAYER TUNNEL

An atmospheric wind tunnel was built in 1972-73 and was upgraded in 1993 with a new fan/motor and speed control unit. This tunnel can be described as an open-circuit type, having a length of 20.42 m (67 ft). The test section has a 1.524 m x 1.524 m (5 ft x 5 ft) cross section and is 10.67 m (35 ft) in length. The tunnel has several features which make it unique compared to other atmospheric tunnels. The majority of existing facilities extract the turbulent fluctuating energy from the mean flow by using roughness elements at the wall as well as obstacles in the mean flow. In Notre Dame's tunnel, arrays of symmetrical side jets in a turbulence box located ahead of the test section are used; thus, the turbulent fluctuating energy is not exclusively extracted from the mean flow. Another important feature is that the strength, as well as the distribution of the jets, can be controlled. This tunnel has been used to produce a simulated atmospheric surface layer with the proper characteristics. The tunnel can also be operated as a conventional low-speed/low-turbulence tunnel with a maximum speed of 15.24 m/s (50 fps). The flow quality is excellent when operated in this manner.

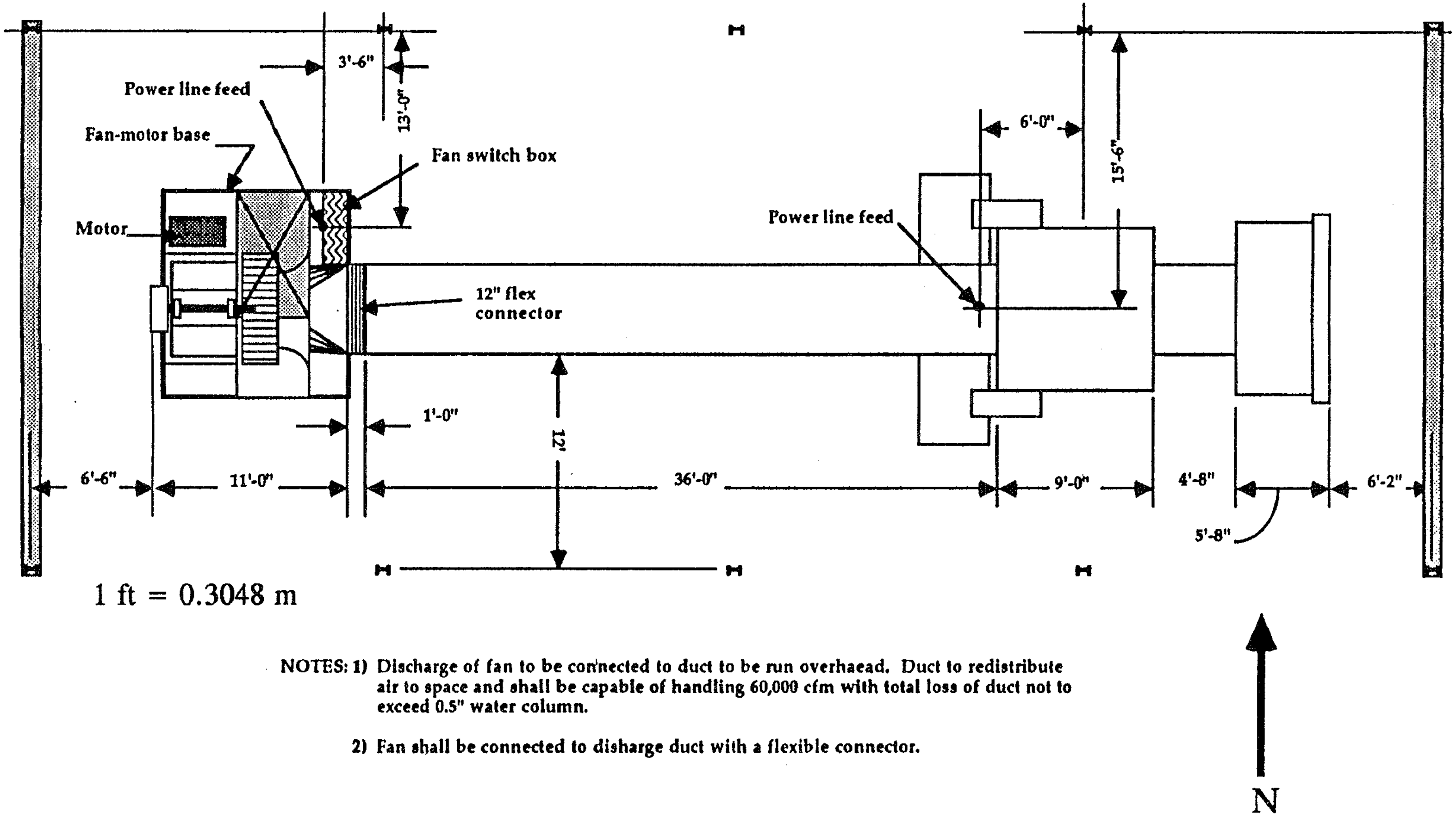
THREE-COMPONENT LDV SYSTEM

Confluent boundary-layer flow field measurements will be performed non-intrusively with an Aerometrics Inc., 3-component Laser Doppler Velocimeter System equipped with an Aerometrics Doppler Signal Analyzer (a high-speed, frequency-domain signal processor). This state-of-the-art LDV system will be used to acquire the u'(x,t), v'(x,t) and w'(x,t) digital time-series required to fully characterize the actively generated turbulence.



Note: 1 ft = 0.3048 m

Figure 1. Hessert Center for Aerospace Research - First Floor Plan.



NOTES: 1) Discharge of fan to be connected to duct to be run overhaead. Duct to redistribute air to space and shall be capable of handling 60,000 cfm with total loss of duct not to exceed 0.5" water column.

2) Fan shall be connected to disharge duct with a flexible connector.

Figure 2. The 1991 Version of the Notre Dame Atmospheric Wind Tunnel.

TEXAS A&M UNIVERSITY
DEPARTMENT OF CIVIL ENGINEERING
DEPARTMENT OF ARCHITECTURE

AREAS OF INQUIRY

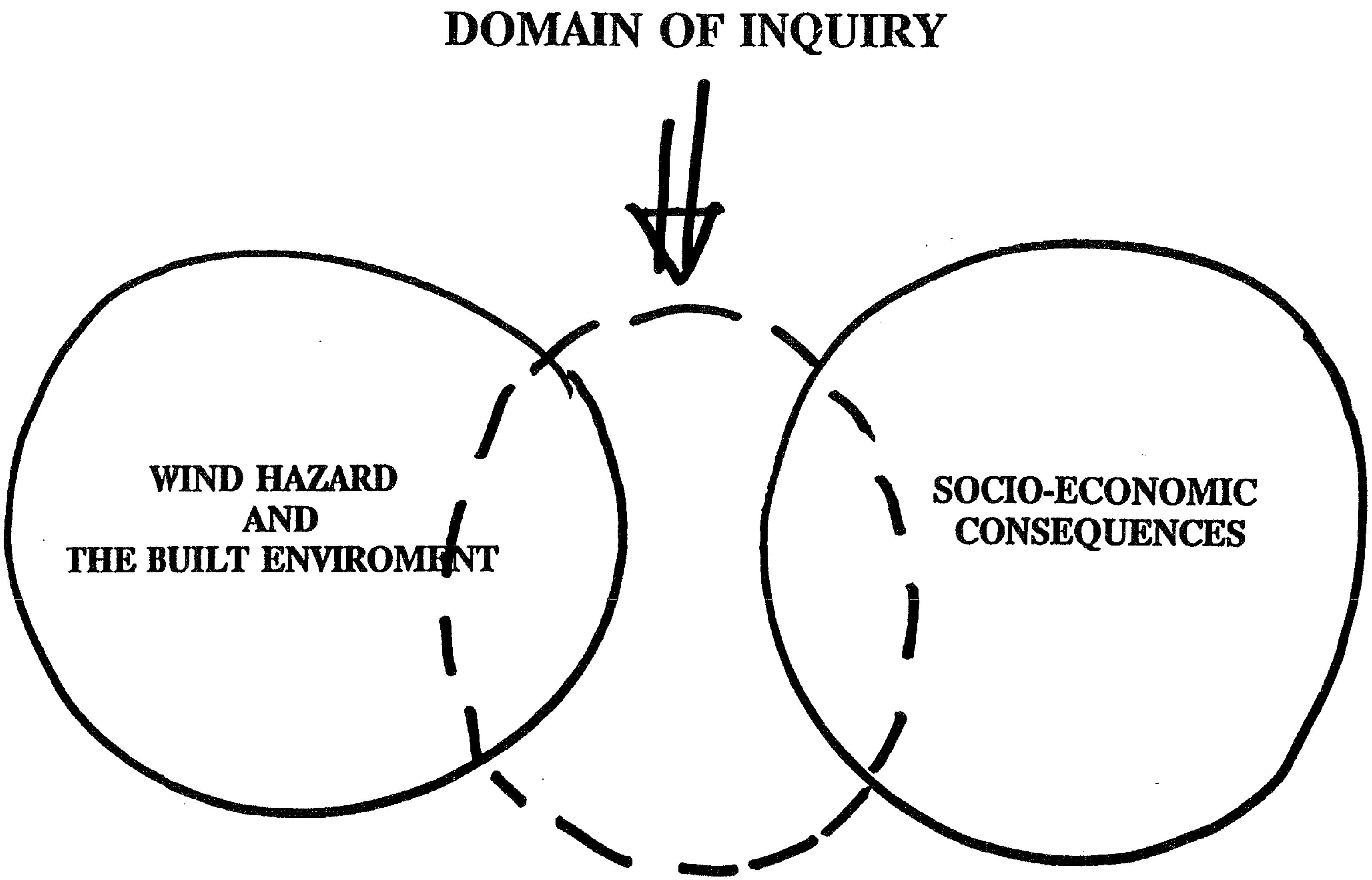
- Damageability models for structural damage
- Damageability models for content damage
- Cost-benefit analyses
- Expert evaluation systems for non-engineers
- Evaluation of cost-effectiveness of building codes
- Evaluation of feasibility of retrofitting options
- Economic evaluation of mitigation alternatives
- Occupant safety

TOOLS USED TO PERFORM ANALYSIS

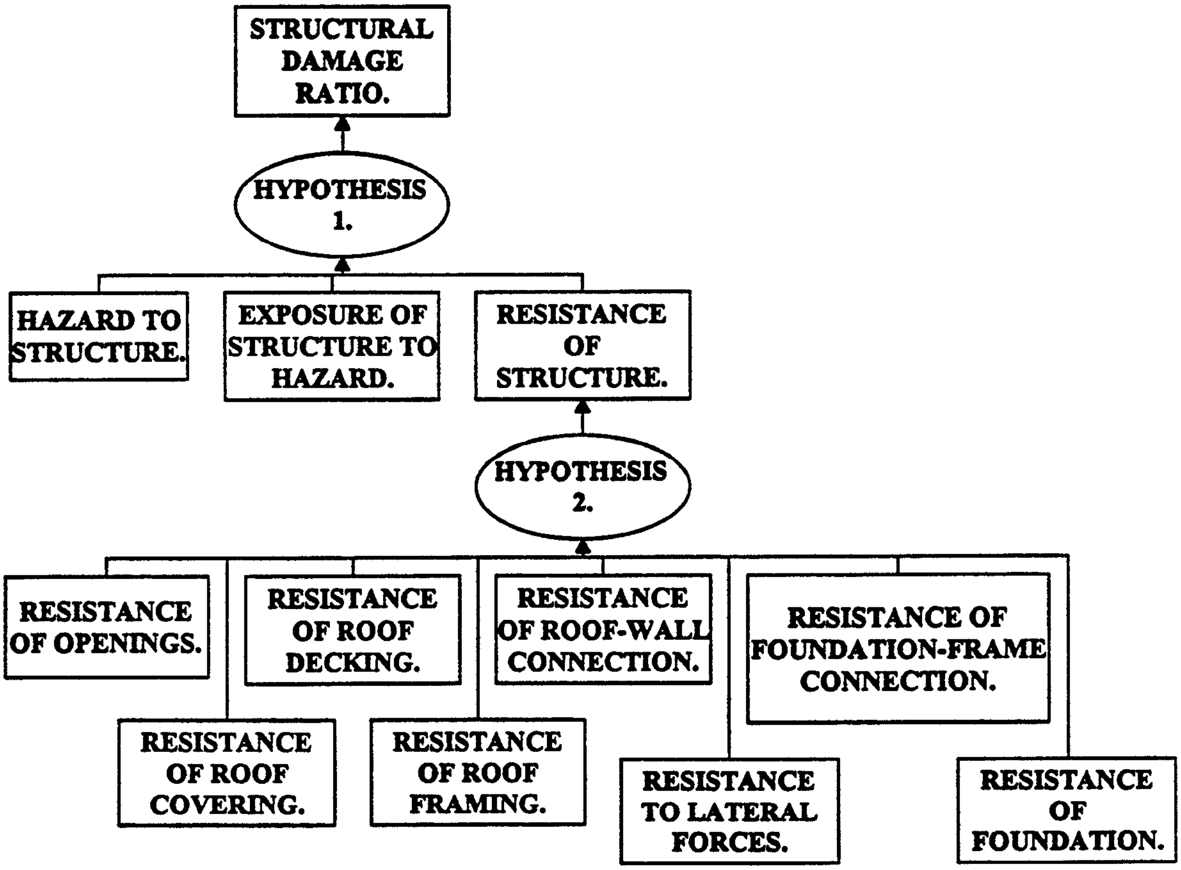
- Wind engineering
- Post-disaster analysis
- Damageability analysis
- Reliability analysis
- Fuzzy logic
- Neural networks
- Decision analysis
- Expert systems
- Engineering economic analysis

ECONOMIC EVALUATION OF MITIGATION ALTERNATIVES

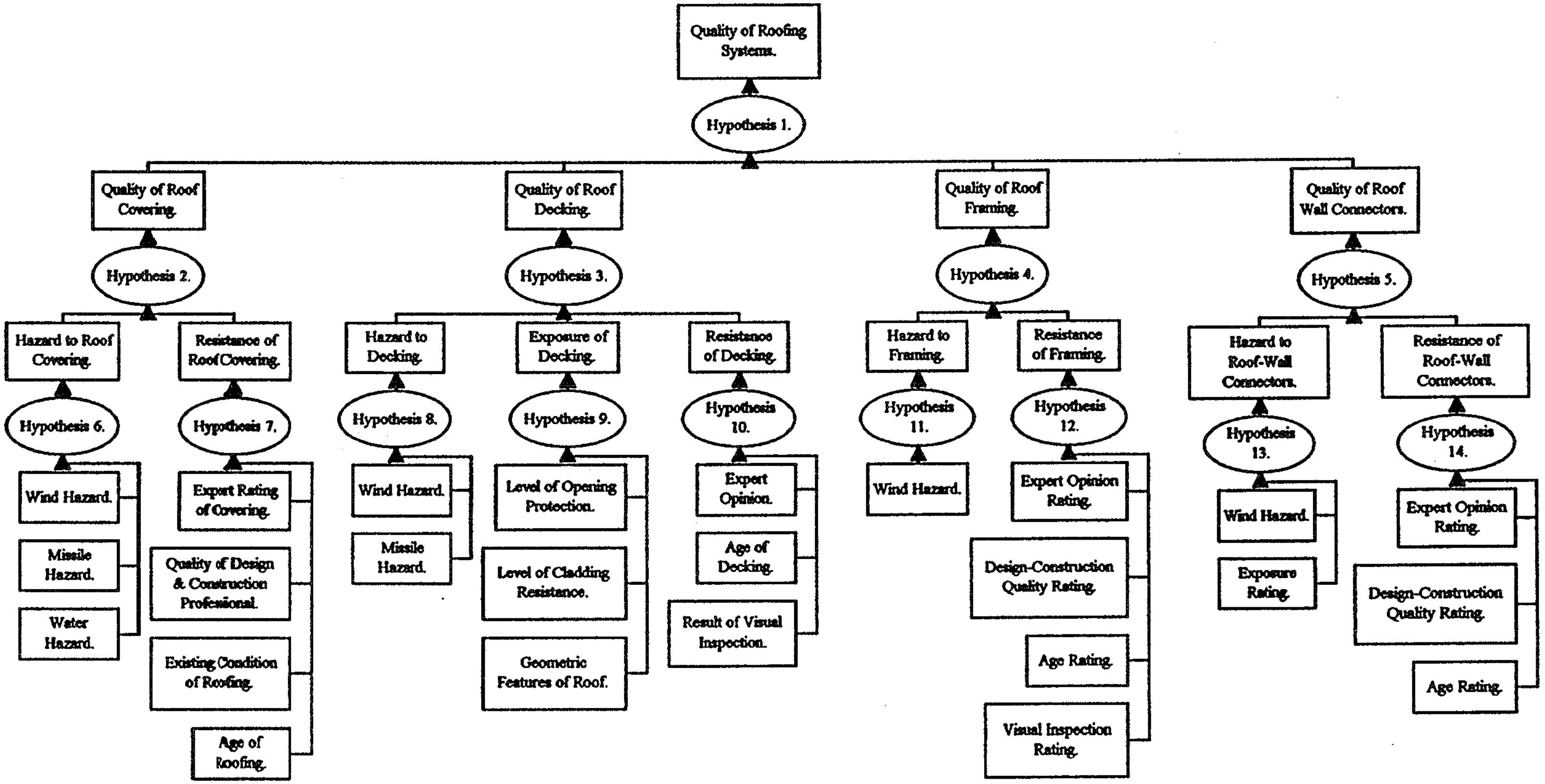
- Impact of window failure
- Impact of engineering the envelope
- Impact of implementing hurricane straps
- Impact of implementing plywood shearwalls
- Impact of bracing gable walls


DOMAIN OF INQUIRY
WIND HAZARD AND THE BUILT ENVIROMENT
SOCIO-ECONOMIC CONSEQUENCES

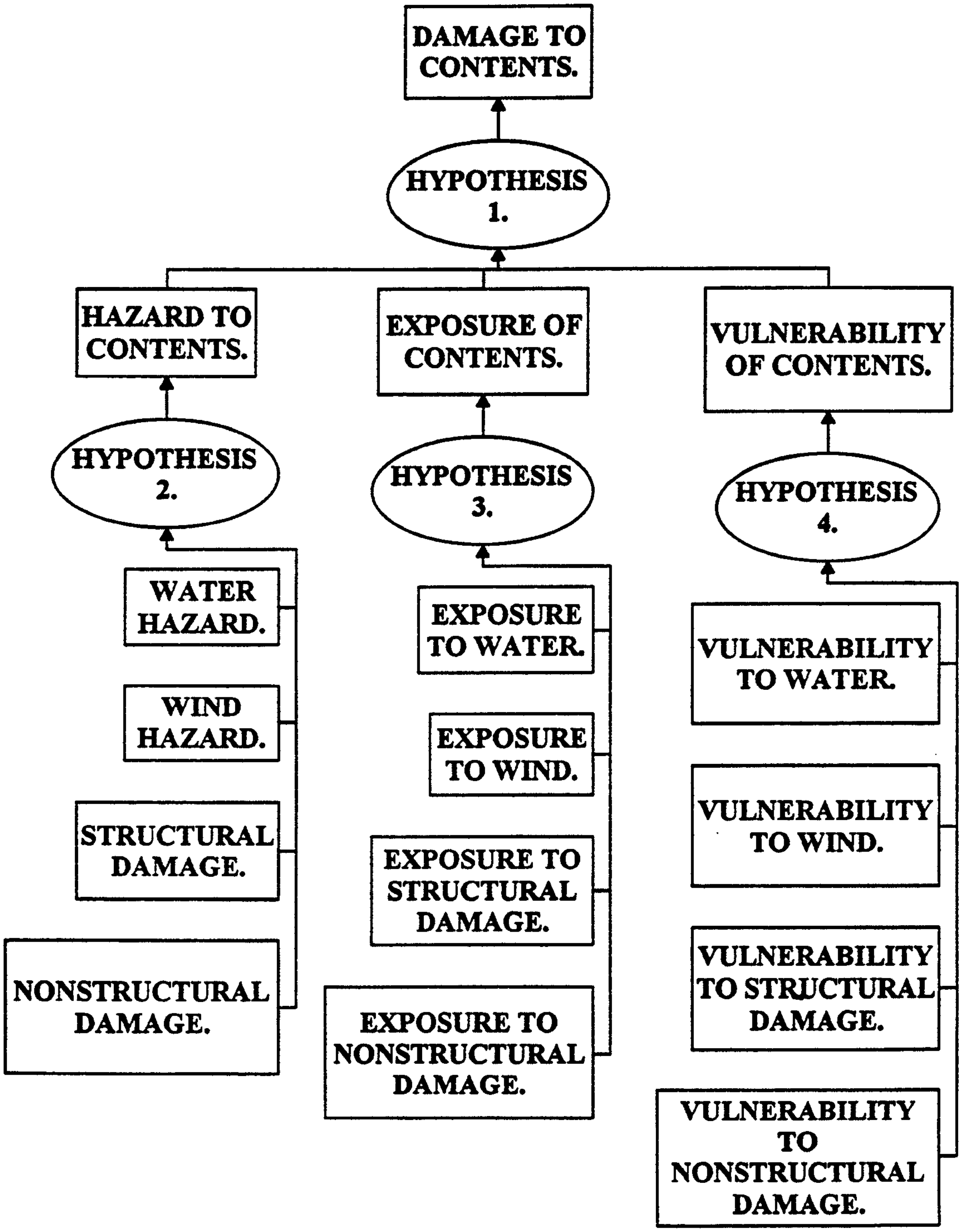
STRUCTURAL DAMAGE RATIO



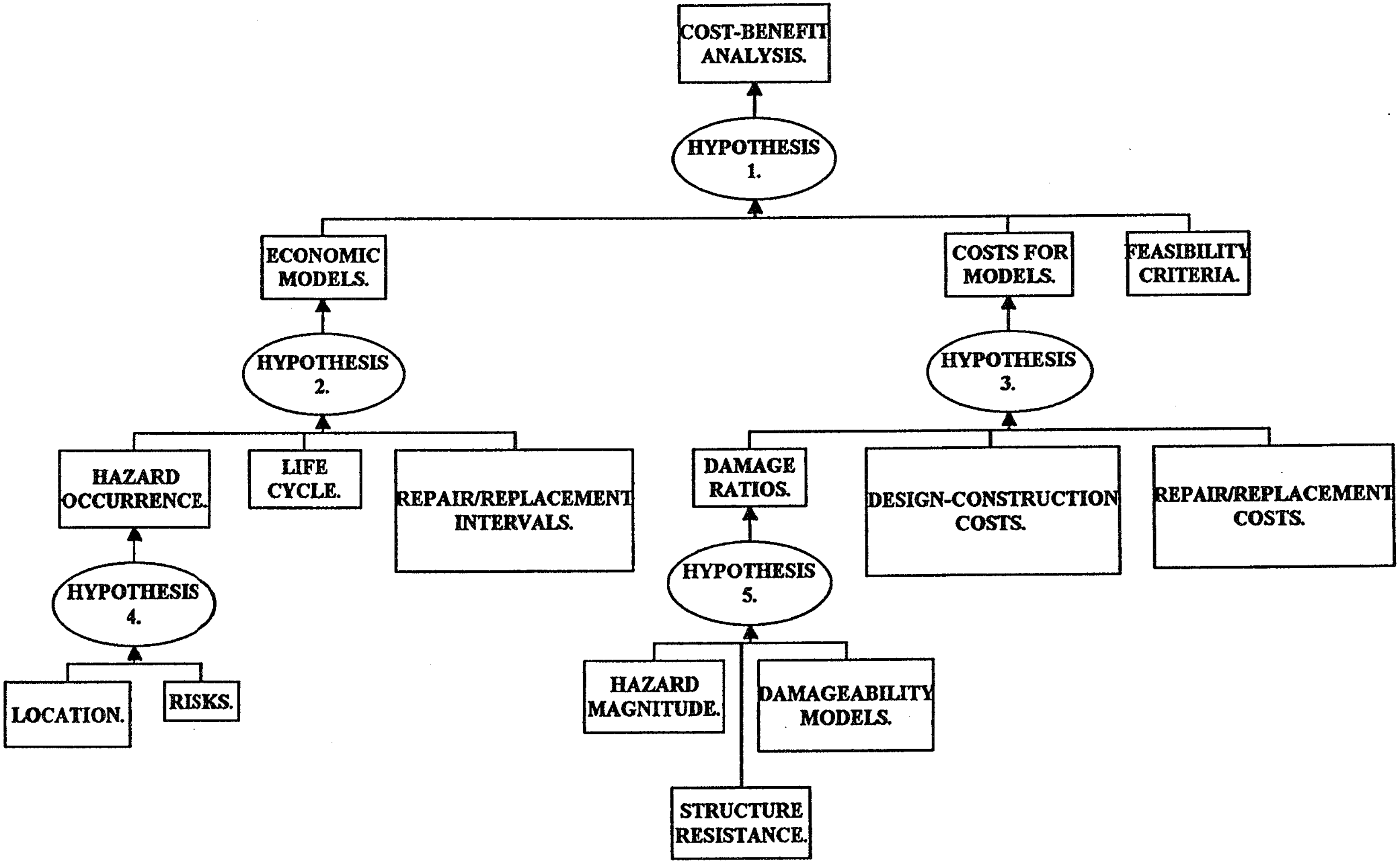
QUALITY OF ROOFING SYSTEMS



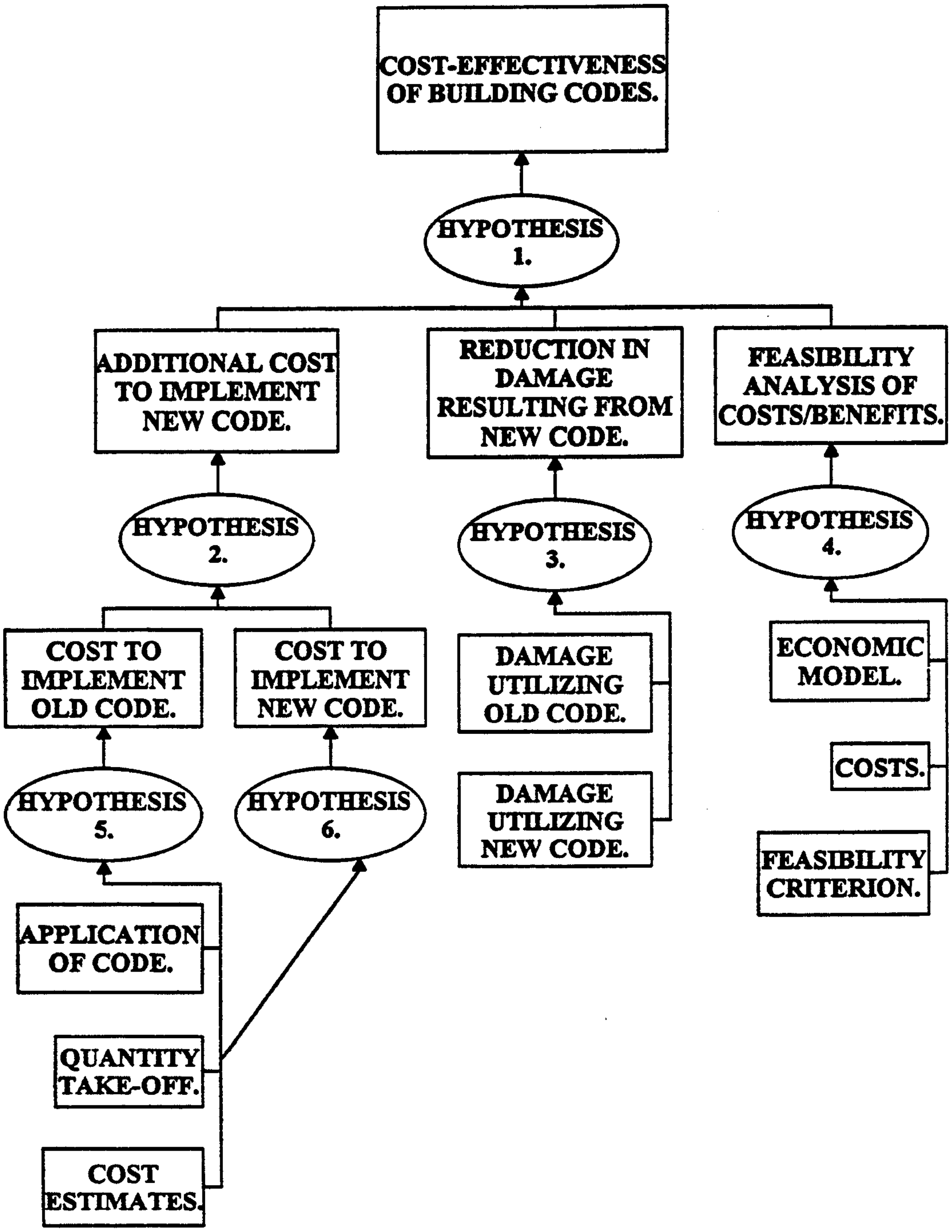
DAMAGE TO CONTENTS



COST-BENEFIT ANALYSIS



COST-EFFECTIVENESS OF BUILDING CODES



TEXAS TECH UNIVERSITY
WIND ENGINEERING RESEARCH CENTER
INSTITUTE FOR DISASTER RESEARCH

Wind engineering research at Texas Tech University has been pursued since 1970, and in September 1988, the Wind Engineering Research Center was established to coalesce existing wind engineering research and to promote university-wide multidisciplinary research. Since the creation of the Center, wind engineering research activities have expanded significantly in various academic departments, and a multidisciplinary approach has been pursued.

Research projects include design of roofing and buildings against hurricanes and tornadoes, soil erosion, gust effects on transport vehicles, vibration of traffic light structures, an expert system to predict wind damage, computational fluid dynamics, and others. A common component of all these projects is wind and its effects on structures and the environment.

MAIN WIND ENGINEERING RESEARCH FACILITIES

Wind Engineering Research Field Laboratory - This facility has three main components: a test building, a data acquisition building, and a tower for mounting meteorological instrumentation. The test building is a 18.14 x 13.71 x 3.96 m (30 x 45 x 13 ft) metal building which can be rotated to provide positive control over the wind angle of attack. Wind pressures on the building are measured by using differential pressure transducers. The data acquisition system is housed in a concrete block building located within the test building. It consists of a 20 MHz, 80386-based PC with 8 MB RAM and a math coprocessor. A 49 m (160 ft) tall guyed tower is used as a platform for the meteorological instrumentation. Wind speed, wind direction, temperature, barometric pressure, and relative humidity are measured with instruments located at the 1, 2, 4, 10, 20, and 49 m (3, 8, 13, 33, 70 and 160 ft) levels.

Wind Tunnel and Tow Tank - These facilities are used to determine flow around buildings and structures as well as to measure pressures on various surfaces. The wind tunnel test section is 0.914 x 1.524 m (3 x 5 ft) with a length of 11.58 m (38 ft). It is powered by a 37.3 kW (50 hp) blower. The tow tank is 4.572 m (15 ft) wide, 3.048 m (10 ft) deep, and 24.38 m (80 ft) long. It can test a full-size automobile at a speed of 3 m/s (10 fps) (equivalent to a wind speed of 45 m/s (100 mph)). A computer-based data acquisition system permits assessment of pressures and forces. The use of color dye in the water allows flow visualization and recording on video cameras.

Tornado Missile Impact Facility - This facility consists of an air-actuated cannon and a reaction frame for supporting the test barriers and is used to study the effects of tornado missile impact on common building materials. The cannon is capable of accelerating a 2 x 4 timber plank weighing 6.8 kg (15 lbm) up to speeds of 67 m/s (150 mph).

SIGNIFICANT ACCOMPLISHMENTS

- Design of in-residence shelters in houses and occupant-protective areas in buildings.
- Damage documentation archive of 70 windstorm events.
- Correcting National Weather Service advisories for severe storms.
- Guiding development of national wind load standard, ANSI A58.1-1982, ASCE 7-88 and ASCE 7-95.
- Establishment of the Wind Engineering Research Field Laboratory (WERFL).
- Development of tornado cannon for studying debris impact.
- NSF-funded CSU/TTU Cooperative Program in Wind Engineering (CPWE).
- Tornado design standard and guide for DOE facilities.
- Development of expert system to evaluate building damage potential for insurance industry.
- Professional seminars, short courses, and student education.

ON-GOING RESEARCH

- Full-scale wind and pressure measurements
- Cooperative research program with CSU
- Wind-borne missile impact testing
- Building categorization for wind resistance
- Wind effects on low-rise buildings
- Effects of natural wind on roofs and roofing systems
- Wind effects on traffic signal structures

RESEARCH AND TESTING FACILITIES

- Wind Engineering Research Field Laboratory
- Tow Tank
- Wind Tunnel
- Tornado Missile Cannon
- Structural Testing Laboratory
- Glass Testing Laboratory

SUPPORT FACILITIES AND RESOURCES

- Wind Library
- Damage Documentation Data Base
- Publication Service
- Computer Resources

WIND ENGINEERING PERSONNEL

- Eleven faculty in Civil, Chemical and Mechanical Engineering, Computer Science, Architecture and Meteorology
- Four Research Associates
- Twenty-four graduate students (MS and PhD)
- Fifteen undergraduates
- Two technicians
- Four clerical and CAD staff

RESEARCH SPONSORS

- National Science Foundation
- Insurance Institute for Property Loss Reduction
- U.S. Department of Energy
- Roofing Industry
- Texas Department of Insurance
- State of Texas
- Texas Tech University (Enhancement)
- Texas Department of Transportation

FUTURE RESEARCH THRUSTS

- Full-scale wind effects on low-rise buildings
- Damage documentation data base
- Full-scale tests on roofing systems
- Expert systems related to wind design
- Improvements in wind resistance of housing and manufactured homes
- Retrofit
- Stochastic analysis of wind and pressure data

UNIVERSITY OF MISSOURI-ROLLA
BUILDING ENVELOPE RESEARCH LABORATORY

The Building Envelope Research Laboratory at the University of Missouri-Rolla is dedicated to research that focuses on understanding and improving the structural performance and durability of building envelope systems. Such research is a vital concern for architects, engineers, and building owners.

The laboratory features state of the art facilities for full-scale tests of the following:

- Dynamic Racking of Curtain Wall Systems
- Wind Loading and Wind-Borne Debris Impact Simulations on Architectural Glass and other Wall/Roof Elements
- Accelerated Weathering

SEVERE WINDSTORMS

Hurricanes and tornadoes impose severe loadings on building envelopes in terms of wind-borne debris impacts and wind-induced dynamic pressures. The Wind Loading Test Facility is capable of simulating wind-borne debris impacts and subsequent positive and negative wind pressure sequences on full-scale curtain wall panels and roof elements.

Size: 3.05 m W x 3.05 m H (10 ft W x 10 ft H)

EARTHQUAKES

To simulate earthquake effects on building envelopes, the Dynamic Racking Test Facility was developed to produce a wide spectrum of in-plane, out-of-plane, and torsional motions on full-scale curtain wall assemblies. The 98 kN (22 kip) system actuator is computer controlled and has a maximum range of ± 76 mm (± 3 in) at 0.5 Hz.

Size: 6.10 m W x 3.66 m H (20 ft W x 12 ft H)

WEATHERING

Weathering is an important determinant of the long-term safety and serviceability of building envelope systems. To simulate and accelerate the effects of Mother Nature, the Accelerated Weather Chamber can be programmed to conduct long-term cyclic weathering tests on full-scale specimens. Chamber capabilities include:

- Temperature (-34°C to 99°C) (-30°F to 210°F)
- Humidity (20 % to 95 % RH)

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY DEPARTMENT OF ENGINEERING SCIENCE AND MECHANICS

Post-disaster investigations consistently show that much of the damage to low-rise structures from hurricanes and other strong wind conditions is due to envelope failures on roofs, cladding and glazing. The excessive damage to non-engineered structures such as dwellings and light industrial buildings must be attributable not only to excessively high wind speeds, inferior building materials, poor construction practices, inadequate inspection, and substandard workmanship, but also to a great extent to deficient code requirements. Design loads for winds on low-rise structures are primarily obtained from building codes which in turn are ultimately based on wind tunnel model studies.

At present, the general understanding of the characteristics and causes of extreme peak suction pressures observed on the roofs of prototype experimental buildings, specifically near corners and leading edges, is inadequate. Comprehensive knowledge of the aerodynamics of wind loading on structures is of critical importance to upgrading the provisions of the ASCE 7-88 standard which is currently deficient in its pressure coefficients for flat roofs and possibly for other types of roofs as well. This flat-roof deficiency is illustrated clearly in Figures 1 and 2. They show that the full-scale peak pressure coefficients from the WERFL experimental building at Texas Tech University exceed the provisions of ASCE 7-88 for tap 50501 in Zone 2 85 % of the time, and for tap 50101 in Zone 3 50 % of the time. The range of azimuth angles for which these peak suctions are observed to exceed the ASCE 7-88 provisions is not as narrow as some wind engineers would have us believe, but instead extends over 90 degrees at each corner, or 360 degrees for an isolated building. The observations are corroborated in Tables 1 and 2 where full-scale pressure coefficients (C_{Pmean}, C_{Prms} and C_{Ppeak}) are compared with the results of, among others, the University of Western Ontario Phase II, this being one of the primary sources for the provisions of the standard (see ASCE 7-88, commentary p. 65).

Another aspect of building aerodynamics is the assumption that the mean and fluctuating surface pressures on the structure's envelope are the result of the dynamic interaction of large-scale wind gusts with the structure. This assumption automatically implies that the small-scale turbulence does not play an important role. This process is generally referred to as "buffeting", and research has shown that it controls the surface pressure for those parts of the envelope where mean pressures are positive. The pressure distributions associated with buffeting can be predicted with quasi-steady theory or can be modeled in the wind tunnel, provided the mean wind and its turbulence (including the large-scale gust structure) in the surface layer are properly reproduced.

However, on those parts of the envelope where mean pressures are negative, the aerodynamic forces are the result of a complex "interaction" of the structure with the flows adjacent to it. These include separated flows, shear layer development, reattachment and, most importantly, vortex formation. Experiments have revealed that observed peak suction pressures are intimately connected with the proximity of the vortex formation and in particular the strength of these vortices. The separated shear layers and their associated vortices are primarily controlled by incident turbulence at scales which are equivalent to the shear layer thickness. These eddies are considered to have the best ability to modify the separated shear layers and therefore control the pressure distribution on adjacent surfaces. Currently, no definite theoretical explanation is available for the correlation of the velocity field of the vortices with turbulence (eddies of all sizes) in the incident flow and with the resulting peak surface pressures. Nevertheless, experimental evidence has revealed that the flow phenomena which produce the extreme suction pressures near roof corners and leading edges appear to be primarily controlled by the intensities of the longitudinal and lateral turbulence components and their small-scale turbulence content (see work by Bearman, Gartshore and Melbourne). Although the details of this process are not well understood, it has become evident that with a combination of:

(a) Free stream turbulence with adequate levels of small-scale turbulence,
(b) Leading edge discontinuities (e.g. roof corners, sharp leading edges and roof ridges), and,
(c) Oblique azimuth angles,

the conditions are favorable for the existence of strong vortices resulting in extremely low suction on the adjacent surface. Experimental evidence presented in Table 3 reveals that emphasizing the duplication of only the longitudinal turbulence distribution in the surface layer and appropriate scaling of the turbulence integral scale are insufficient for the successful reproduction of the extreme suctions observed near the corners and leading edges on the roof of the WERFL experimental building (Figs. 3 and 4). Moreover, recent analysis of records from pressure taps located under the corner vortices and under the separation bubble has revealed that the quasi-steady approach to predict fluctuating pressures in these areas does not work.

To seek solutions to these major problems in building aerodynamics, current and proposed research at Virginia Tech and at Clemson University is addressing the following tasks:

1. Ascertain a complete understanding of the mean and fluctuating velocity fields of the separated shear layers and associated vortex flows adjacent to the building surface.
   (a) Define those parameters of the incident flow which affect these flows.
   (b) Investigate how the vortex flows affect the pressures on adjacent surfaces.
   These investigations are expected to lead to improvements in physical flow simulations by defining the critical mean flow and turbulence parameters to be simulated.

2. Develop better wind tunnel simulation techniques with the purpose of being able to predict wind loads and pressure forces on low-rise structures, particularly those in separated flow regions. These techniques should not only lead to improvement in the prediction of the intensity of the wind pressures, but also adequately simulate their duration and spatial distribution acting on critical elements of the roof corner, roof sheathing and cladding.

3. Calibrate the pressure coefficients (C_{Pmean}, C_{Prms} and C_{Ppeak}) obtained from the wind tunnel model experiments at Clemson University against the full-scale pressure coefficients observed on the experimental building at the WERFL at Texas Tech University.

4. Once task 3 is achieved, investigate wind loads and surface pressures on a variety of roof geometries and azimuth angles for isolated structures.

5. Study the effect of exposure and surrounding buildings on these wind loads and surface pressures (shielding problem).

6. Simulate the surface-layer flow over any kind of upwind terrain (from flat, smooth and uniform terrain to complex terrain), requiring careful simulation of the incident turbulence (intensity and small-scale content).

7. Analyze the experimental results and make them available for building code revisions. These revisions should include better definitions of wind loads and their associated areas, ultimately leading to improved design and construction to handle these loads under extreme wind conditions.

8. Use Visual Data Compression (VDC) to explore trends and significant relationships between the different variables in the large complex data set of pressure coefficients.

Table 1. FULL SCALE, MODEL SCALE AND CODE

COMPARISON OF EXTREME PRESSURE COEFFICIENTS

TAP #50501 ZONE 2

Tap Coordinates		Pessure Coefficients			Scale	
x/H	y/H	Cpmean	Cprms	Cppeak		
0.364	0.091	-2.8	1.33	-10.5	1:1	Sv/U<20%
0.364	0.091	-2.48	1.32	-9.05	1:25	Simulation IV
0.364	0.091	-2.8	1.2	-9.0	1:50	Simulation V
0.364	0.091	-2.3	0.87	-5.7	1:50	Simulation III
0.563	0.125	-1.09	0.36	-2.9	1:100	UWO Phase II, open
0.125	0.063	-1.71	0.54	-4.94	1:100	UWO Phase II, open
0.563	0.063	-1.0	0.27	-2.82	1:100	UWO Phase II, open
0.364	0.091	-3.3	1.8	-12.0	1:1	Sv/U>20%
0.563	0.125	-0.79	0.40	-3.69	1:100	UWO Phase II, b.up
0.125	0.063	-0.86	0.54	-4.25	1:100	UWO Phase II, b.up
0.563	0.063	-0.83	0.36	-4.0	1:100	UWO Phase II, b.up
zone 2		---	---	-4.4		ASCE 7-88

Table 2. FULL SCALE, MODEL SCALE AND CODE

COMPARISON OF EXTREME PRESSURE COEFFICIENTS

TAP #50101 ZONE 3

Tap Coordinates		Pessure Coefficients			Scale	
x/H	y/H	Cpmean	Cprms	Cppeak		
0.091	0.091	-1.8	1.05	-10.0	1:1	Sv/U<20%
0.091	0.091	-1.96	0.85	-8.5	1:25	Simulation IV
0.091	0.091	-2.0	0.94	-8.3	1:50	Simulation V
0.091	0.091	-1.7	0.73	-4.3	1:50	Simulation III
0.125	0.125	-1.11	0.43	-3.89	1:100	UWO Phase II, open
0.063	0.063	-1.36	0.53	-4.50	1:100	UWO Phase II, open
0.091	0.091	-1.8	1.35	-12.0	1:1	Sv/U>20%
0.125	0.125	-0.81	0.42	-3.75	1:100	UWO Phase II, b.up
0.063	0.063	-0.97	0.54	-5.19	1:100	UWO Phase II, b.up
zone 3		---	---	-6.8		ASCE 7-88

Table 3 WERFL: flow parameters and roof pressures comparison.

Simulation	I	II	III	IV	V	VI
Scale	1:100	1:100	1:50	1:25	1:50	1:1
TIu,% at z=4m	20.0	24.9	21.7	21.5	20.3	19.2
TIu,% at z=10m	16.0	21.4	17.2	18.5	19.0	16.9
TIv,% at z=4m	19.7	19.7	16.8	21.0	15.2	16.8
TIv,% at z=10m	15.7	15.7	12.3	16.0	13.5	13.4
Lux,m at 4m	40	68	58	28	29	---
Lux,m at 10m	60	141	52	22	23	75
Tap 50101:						
Cprms (max)	0.437	0.769	0.722	0.85	0.958	1.07
Cppeak (min)	-2.79	-4.9	-4.4	-8.5	-8.22	-9.9
Tap 50501:						
Cprms (max)	0.569	0.807	0.882	1.32	1.24	1.37
Cppeak (min)	-4.21	-5.62	-5.75	-9.05	-9.22	-10.5

Simulation	Details	Emphasis
I	Vanes, spires and 15 mm pegs	TIu and constant stress layer.
II & III	Vanes, spires and chains	TIu, Lux and constant stress layer.
IV	Vanes,walls and large blocks	TIu, TIv and small scale turbulence.
V	Spire-roughness and small spires directly upstream of model.	TIu, TIv and small scale turbulence.
VI	Full scale WERFL	TIv < 20%

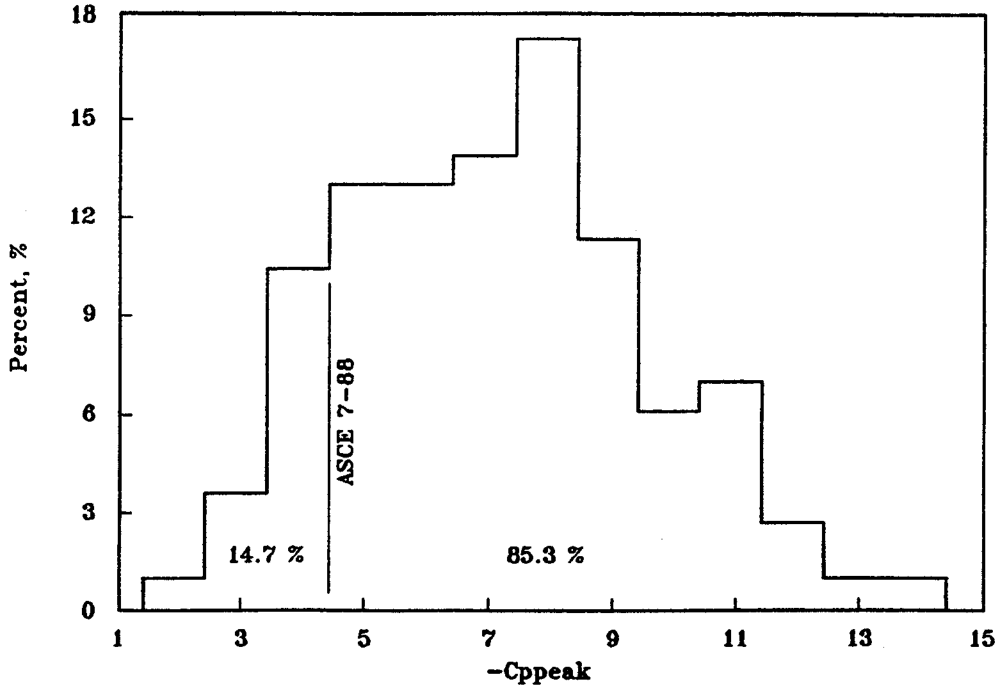


Figure 1. Distribution of observed negative peak pressure coefficients for tap #50501 and wind azimuth angles between 180 and 270 degrees.

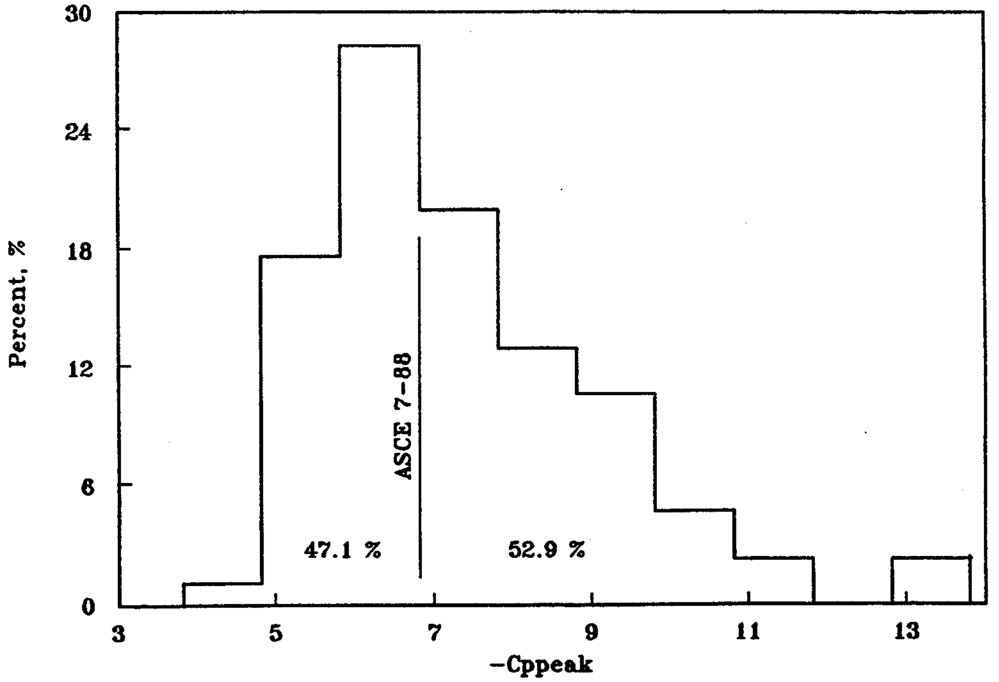


Figure 2. Distribution of observed negative peak pressure coefficients for tap #50101 and wind azimuth angles between 180 and 270 degrees.

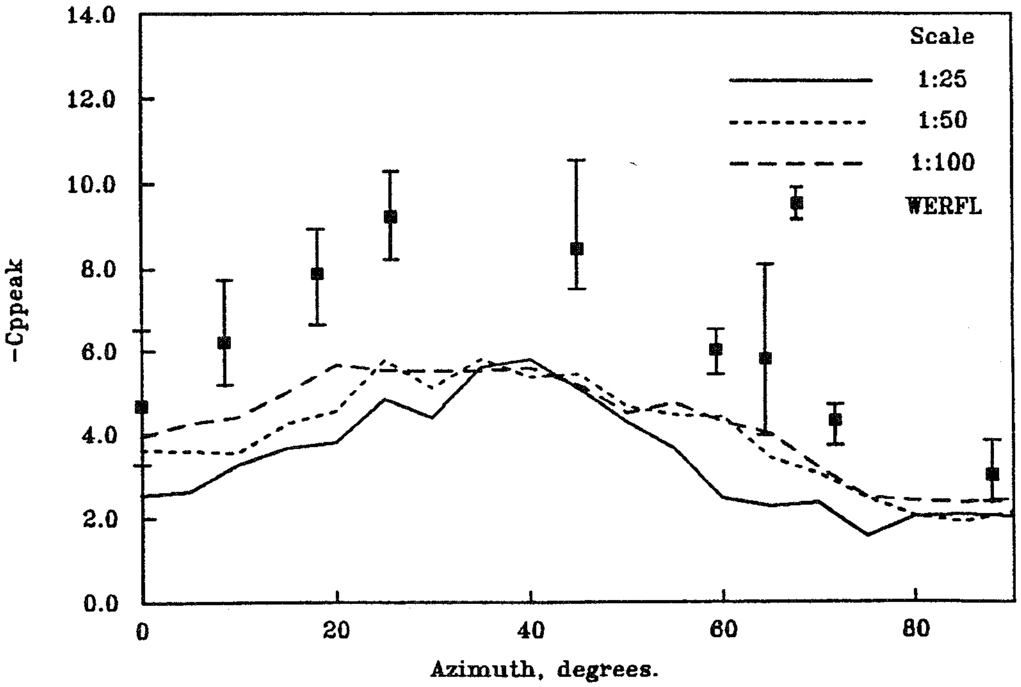


Figure 3. Peak pressure coefficient comparison (Tap # 50501, Sv/U < 20%) for full scale (WERFL) and model scale (flow simulation as II and III).

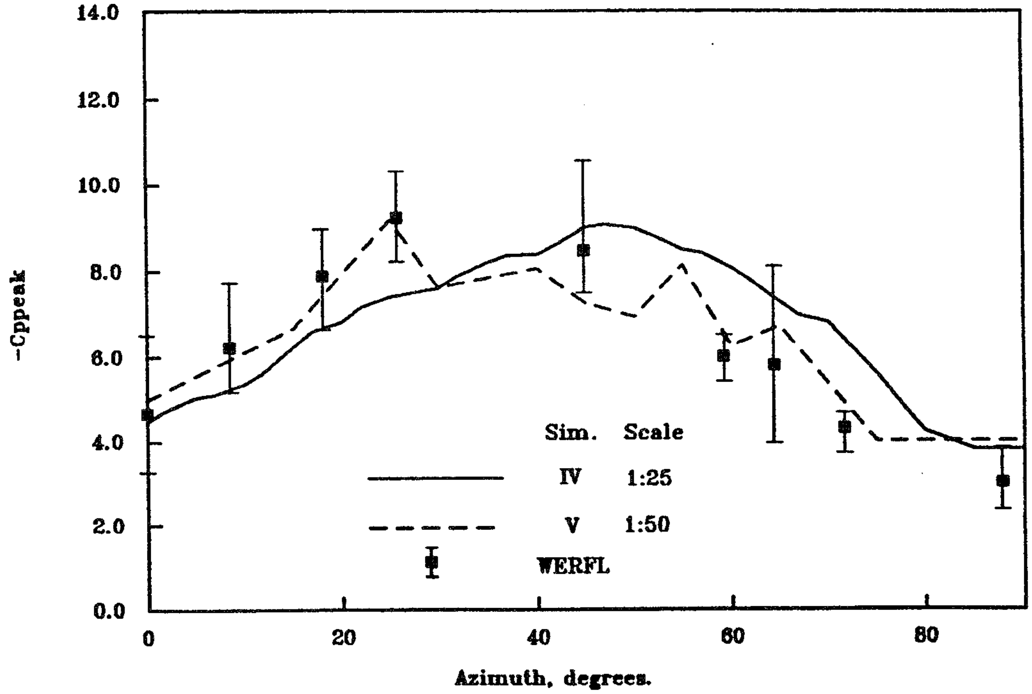


Figure 4. Peak pressure coefficient comparison (Tap # 50501, Sv/U < 20%) for full scale (WERFL) and model scale (flow simulation as IV and V).

MULTI-UNIVERSITY RESEARCH PROJECT

LATERALLY LOADED MANUFACTURED HOMES

PROJECT ORGANIZATION

South Dakota School of Mines and Technology (James Goodman)
University of Wyoming (Richard Schmidt)
Colorado State University (Marvin Criswell)
Engineering Data Management (Andrew Steward)

Phase I - June 1993 - December 1995

Phase II - Verification of Mathematical Models Through Full-Scale Tests

Project goal: Develop a verified rational structural analysis procedure for laterally loaded manufactured homes.

Current design - based on conventional "stick built" light frame timber construction.

Needed - analysis considering 3-D system behavior recognizing characteristics of manufactured homes.

- o Torsion box behavior
- o Use of "rigid" glues
- o Connection details
- o Manufacturing processes

PHASE I - DEVELOPMENT OF MATHEMATICAL MODELS

PHASE I OBJECTIVES

1. Determine and evaluate current industry practices and material properties.

2. Conduct appropriate component tests to obtain properties for use in analyses.

3. Develop a rational 3-D mathematical model for complete (i.e. 3-D system) structural analysis of laterally-loaded manufactured homes.
   - Finite elements
   - Desk top computing

PHASE I APPROACH

Use geometry, materials, data from 1987 test of "Crownpointe" manufactured home at

Fleetwood Company site (Goodman, Steward, Salsbury)
- o Airbag loading - one side of structure.

Activities

South Dakota School of Mines and Technology - Overall coordination, connection tests

University of Wyoming - Formulation of 3-D model (Polo-Finite nonlinear FEA), Evaluation of model performance.

Colorado State University - Examination of design practices, Library of relevant literature, Testing of mathematical model.

EDM - Examination of industry practices, Component testing, Material input values.

Project Advisory Board

Industry
Government
Regulatory

Safety and Performance of Manufactured Homes depends upon:

- o Structural strength of manufactured unit
  - Overall structural system strength
  - Details, connections, fastenings
  - Construction practices

- o Accurate description of wind environment/loads
  - As represented in code provisions
  - As described for site location

- o Strength of anchorage (tiedown) systems
  - Geotechnical aspects
  - Structural strength of anchors
  - Installation, inspection

- o Design philosophy, target reliability
  - How safe is safe enough? Cost effective?

- o Non-traditional "loadings"
  - Impact by debris, including tree falls
    - o Direct structural damage
    - o Openings plus increase of internal pressure

- Effects of nonstructural, secondary structure
    - o Carports, awnings, attached structures

MAJOR RESEARCH FACILITIES

Project Phase I not facilities intensive

o University Structural Testing Laboratories
  Fairly typical component/materials testing
    - South Dakota School of Mines and Technology
    - University of Wyoming
    - Colorado State University

  Frames and rigs for large-scale tests
    - Colorado State University

o Industry Structural Laboratories
  EDM
    - Structural components, trusses and small assemblies
    - Wood properties

  Fleetwood Enterprises
    - Shear wall tests
    - Airbag lateral load tests

  Wind tunnel Facilities Available at Colorado State University
    - Wind tunnel tests not included in current Phase I or planned Phase II

FUTURE RESEARCH THRUSTS

Phase 2 - Verification of Mathematical Model Through Full-Scale Tests

Tasks:

1. Selection of manufactured homes for full-scale testing.

2. Define/measure component and material properties.

3. Full-scale testing - later loads (@ Fleetwood - California)

4. Data analysis, verification of mathematical model by comparison with test results.

5. Initial development of simplified design provisions for use in design codes & practices.

6. Some parameter & design studies.

OTHER NEEDED FUTURE WORK

A. Coordination/cooperation with wind engineering projects specifically addressing wind forces on isolated and grouped units.

B. Definition of how to most effectively increase manufactured home performance
   - o major component design
   - o improvement of connections, details
   - o local strengthening in areas of high pressure

NATIONAL ROOFING CONTRACTORS ASSOCIATION ROSEMONT, ILLINOIS

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McDonald, J.R. and Smith, T.L., *Performance of Roofing Systems in Hurricane Hugo*, August 1990.

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Proceedings of the Roof Wind Uplift Testing Workshop, November 1989.

Wind Design Guide for Ballasted Single-Ply Roofing Systems, ANSI/RMA/SPRI RP-4, 1988.

Minor, J.E., "Performance of Roofing Systems in Wind Storms," *Proceedings of the Symposium on Roofing Technology*, September 1977, pp. 124.

Kind, R.J. and Wardlaw, R.L., *Design of Rooftops Against Gravel Blow-Off*, National Research Council of Canada, Report No. 15544, September 1976.
Note: This report is summarized in the *Proceedings of the Symposium on Roofing Technology*, September 1977, pp. 112.

FOREST PRODUCTS LABORATORY
ENGINEERED WOOD PRODUCTS AND STRUCTURES
MADISON, WISCONSIN

At the present time, FPL does not have any active studies aimed specifically at evaluating wind resistance. We are, however, looking into the use of composite materials comprising recycled wood in matrices of cement or plastic which have potential for resisting wind-blown missiles as well as good damping and energy dissipating properties. This seems to be the direction we will be taking over the next 3 to 5 years in relation to wind and seismic design of residential building systems.

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
DIVISION OF AFFORDABLE HOUSING RESEARCH AND TECHNOLOGY
WASHINGTON, DC

SELECTED PUBLICATIONS

WIND LOADS

Assessment of Damage to Single-Family Homes Caused by Hurricanes Andrew and Iniki. NAHB Research Center, September 1993.

Wind Load Provisions of the Manufactured Home Construction and Safety Standards - A Review and Recommendations for Improvement. NIST, May 1993.

Manufactured Home Construction and Safety Standards on Wind Standards; Final Rule. HUD, January 14, 1994.

FOUNDATIONS

Permanent Foundations Guide for Manufactured Housing. Building Research Council - University of Illinois, August 1989.

Frost-Protected Shallow Foundations in Residential Construction - Phase I. NAHB Research Center, April 1993.

Frost-Protected Shallow Foundations in Residential Construction - Phase II - Final Report. NAHB Research Center, June 1994.

Design Guide for Frost-Protected Shallow Foundations. NAHB Research Center, June 1994.

Stemwall Foundations for Residential Construction. NAHB Research Center, March 1993.

ALTERNATIVE MATERIALS

Alternatives to Lumber and Plywood in Home Construction. NAHB Research Center, April 1993.

NATURAL HAZARDS - EARTHQUAKES

Survey of Single Family and Low-Rise Multi-Family Homes in Northridge Earthquake. NAHB Research Center, July 1994.

Survey of Multi-Family High Rise Homes in Northridge Earthquake. NIST, August 1994.

Risk Assessment of HUD Multifamily Homes Subject to Earthquake. USGS.

Earthquake Resistant Bracing Systems - Manufactured Homes. SWA.

FUTURE ACTIVITIES

Update Wind Standards for Zone I (non-hurricane zone) for Manufactured Housing - HUD.

Update Permanent Foundation Handbook for Manufactured Housing - University of Illinois.

Continue and complete wind research on Manufactured Housing, particularly on installation standards - NIST.

Reference latest ASCE 7 wind standards for Single and Multifamily Housing - HUD.

Create prescriptive criteria for steel framing for Single Family Housing - NAHB Research Center.

Publications available from:

HUD USER
P.O. Box 6091
Rockville, MD 20850
1-800-245-2691
(301) 252-5154
FAX (301) 251-5747

NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
STRUCTURES DIVISION
BUILDING AND FIRE RESEARCH LABORATORY
GAITHERSBURG, MARYLAND

The Structures Division has maintained an active program in wind engineering research over the past 25 years. Much of this work has been carried out in response to the engineering needs of other Federal agencies while more generic research activities have been undertaken in support of standards such as ANSI A58.1 (now ASCE 7 - Minimum Design Loads for Buildings and Other Structures). The Structures Division maintains a state-of-the-art structural testing laboratory and an interactive graphics and structural analysis laboratory.

ACTIVITIES AND ACCOMPLISHMENTS IN WIND ENGINEERING RESEARCH

- Engineering micrometeorology
- Engineering wind climatology
- Structural aerodynamics
- Structural aeroelasticity
- Safety of offshore structures to wind effects
- Structural reliability
- Instrumentation and measurement technology
- Full-scale measurements
- Post-disaster investigations

CURRENT WIND ENGINEERING ACTIVITIES

Current NIST-supported activities in wind engineering include assessments of damage resulting from extreme wind events such as Hurricane Andrew and, at the request of the Department of Housing and Urban Development, the development of improved wind load criteria for the design of manufactured homes. In addition, NIST is involved with the development of improved methods for the estimation of extreme value distribution tails, the nonlinear behavior of structures subjected to fluidelastic effects, and the development of expert systems for wind load standards.

APPENDIX A
WORKSHOP PROGRAM

RESEARCH NEEDS IN WIND ENGINEERING

Gaithersburg Hilton Hotel
Gaithersburg, Maryland
September 12-13, 1994

<u>Monday, September 12</u>

0800 Registration

0830 Welcome
Dr. Richard N. Wright, Director
Building and Fire Research Laboratory
National Institute of Standards and Technology

0840 Background information and scope of workshop
Dr. Richard D. Marshall, Leader
Structural Evaluation Group
Structures Division, BFRL, NIST

0850 Presentation of agency/institution program overviews

1000 Break

1020 Continue program overviews

1230 Lunch

1315 Working group sessions

1730 Adjourn

<u>Tuesday, September 13</u>

0830 Preparation of working group reports

1000 Break

1020 Presentation of findings and recommendations

1200 Adjourn

APPENDIX B
WORKSHOP PARTICIPANTS

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