• WIRELESS CHARGING OF ELECTRIC VEHICLES
• STATISTICALLY PREDICTING ELECTRICAL ARcing
• ADVANCED COMPUTER MODELING
• NEW DYNAMICS OF BASEMENT FIRES
NEW CHALLENGES
CALL FOR NEW SCIENCE

Progress is an unstoppable, transformative force. New technologies, product advances and globalization are arriving one on top of another at a dizzying pace. Innovation makes us more efficient, more productive and more connected. But there is a cost, and that cost is risk. To help mitigate the emerging risks, UL is developing New Science. Through fundamental discovery, testing methodologies and equipment, procedures, software and standards, UL is creating new and important ways to make the world a safer place.
NEW SCIENCE: FIRE SAFETY

OVERVIEW

UL’s dedicated team of scientists, engineers and researchers is creating New Science in a variety of ways. From live experiments to computational modeling, statistical analysis to quantification of risk, we are constantly seeking to improve products, techniques, methodologies, processes and standards.

WIRELESS CHARGING OF ELECTRIC VEHICLES, PG.4

UL pioneered a methodology for testing wireless EV chargers. Leveraging our technical expertise and advanced engineering capabilities, we created new computational modeling techniques to gauge safety, compatibility and efficiency.

STATISTICALLY PREDICTING ELECTRICAL ARcing, PG.7

UL engineers are conducting research and using predictive modeling to help quantify risk and advance standards related to electrical arcing. We showcase a broad range of updates on arc-related research initiatives.

ADVANCED COMPUTER MODELING, PG.13

UL is using sophisticated computer modeling to understand and predict how different materials behave in specific situations. We focus on the behavior and structural response of steel fire doors and wood beams in a fire environment.

NEW DYNAMICS OF BASEMENT FIRES, PG.18

Basement fires are among the most challenging and dangerous. UL plays a critical role in examining the hazards associated with various types of residential flooring systems to better understand this important topic.
WIRELESS CHARGING OF ELECTRIC VEHICLES

STATISTICALLY PREDICTING ELECTRICAL ARcing

ADVANCED COMPUTER MODELING

NEW DYNAMICS OF BASEMENT FIRES
WHY WIRELESS CHARGING OF ELECTRIC VEHICLES MATTERS

Given that wireless charging of electric vehicles (EVs) is a high-power application, there are concerns about the risks related to the human body, the environment and property. UL’s research is helping to mitigate safety concerns by developing ways to empirically determine and predict high-risk situations related to wireless chargers and EVs.

CONTEXT

By 2015, there may be as many as 1 million electric-powered vehicles and more than 20 different EV models available for sale in the U.S.¹ It is estimated that sales of wireless charging systems for EVs could surpass 280,000 by 2020.² The growth in the number of electric-powered vehicles will require the development of many new offerings, presenting significant opportunities for automobile manufacturers as well as the manufacturers of power systems used to build and fuel these fleets. A key area of focus is the deployment of an infrastructure to power this generation of high-tech vehicles, including wireless chargers.

WHAT DID UL DO?

UL has been among the pioneers in developing and using new methodologies for testing the safety of wireless chargers for EVs. Using our technical expertise and advanced engineering capabilities, we have created computational modeling techniques that focus on safety, compatibility and efficiency.¹ Computational modeling is more cost-effective than physical testing, has fewer limitations and, most important, enables us to examine more considerations, variables and factors.

Our research methods have demonstrated via simulation the variations in field distribution and efficiency for varying conditions of primary and secondary charger pad alignment in a wireless EV charging system. In addition, when charger paths are misaligned, the danger potentially increases as well, notably in the form of raised radiation levels. The modeling techniques also can help address conditions of compatibility between the primary charger pad (located in the infrastructure) and the secondary pad (located on the vehicle). Compatibility of the two pads is required for the system to work safely and maintain the charging efficiency.
We are using computational modeling to determine the safety impact of the wireless charging zone. The charging zone is located between the primary and secondary pads. When the charging system is running, power is high in this concentrated area. UL is able to model a variety of potential scenarios. For example, what happens if an aluminum soda can accidentally enters the charging zone? Our advanced tools enable us to predict how hot those objects can get, the varying levels of radiation and under

**IMPACT**

UL's simulated research is helping improve knowledge about critical issues for the safety and performance of wireless chargers for EVs. Due to the large area of electromagnetic field exposure between the car and the primary coil/pads and the high electrical power involved in this application, it is critical that the product's safety be carefully evaluated for electrical shock, electromagnetic field exposure levels and fire hazard. Our ongoing efforts to address the science of near magnetic fields for EV wireless charger systems will help bring about a safer future.
WIRELESS CHARGING OF ELECTRIC VEHICLES

STATISTICALLY PREDICTING ELECTRICAL ARCING

ADVANCED COMPUTER MODELING

NEW DYNAMICS OF BASEMENT FIRES
WHY STATISTICALLY PREDICTING ELECTRICAL ARcing MATTERS

Electrical arcing can create significant health and safety risks for home occupants and firefighters. According to a statistical report by the National Fire Protection Association (NFPA), an estimated 44,800 home structure fires reported to U.S. fire departments in 2009 involved some type of electrical failure or malfunction as a factor contributing to ignition. These fires resulted in 472 civilian deaths, 1,500 civilian injuries, and $1.6 billion in direct property damage.\(^5\) Approximately 57 percent of these fires originate from wiring and related equipment.\(^6\) UL is working in the area to prevent loss of life and property. We are using our data to quantify risk, inform code and help shape standards.

CONTEXT

Electrical Fire Safety continues to be a concern, and arcing is a common cause of home building fires. Even if circuit breakers function as they are supposed to, arcing can still occur.

In 2005-2009, home electrical fires represented 13 percent of total home structure fires, 17 percent of associated civilian deaths, 11 percent of associated civilian injuries, and 21 percent of associated direct property damage.\(^7\) Home electrical wiring can be damaged through a number of common occurrences during installation or after. These include over-stapling, crushing, bending, penetration by screws and nails and damage caused by rodents and insects. Elevated temperatures and humidity can also adversely affect cabling over time, which can lead to arcing faults and ignition of combustibles in proximity.

For these important reasons UL is investing its expertise in helping better understand and prevent fires and damage due to electrical arcing, which we define as a luminous charge of electricity across an insulating medium, usually accompanied by the partial volatilization of the electrode.\(^8\)

WHAT DID UL DO?

UL has the long-term goal of advancing fundamental knowledge related to electrical arcing by developing research, new approaches and standards. Recently, we have focused on applying statistical methods to our work. Some key areas of this New Science include:

- The use of parametric data from large sets of arcing data to build statistical models that characterize arcing behavior.
- Identification of the lognormal probability distribution as the key statistical model for peak current and other arcing parameters.
- Identification of the importance of total arc energy release as a primary indicator of material ignition.
- Characterization of expected arcing event lengths based on test conditions.
PARAMETERIZING AND STATISTICAL ANALYSIS OF ARCING DATA

UL has pioneered a key approach involving the use of parameterized data extracted from large (>100,000) sets of arcing data, which is then analyzed using a variety of statistical methods. UL’s analyses have shown that arcing events typically follow statistically understandable patterns, which can be modeled and used for predicting probabilistic outcomes. This information has been particularly helpful in predicting the distribution of real-world systems, such as the arcing current expected in a residential branch circuit with known length and wire size.\(^9\)

The approach involves breaking down arcing events into small units (e.g., a single arcing half-cycle when analyzing residential AC arcing), then extracting single numerical parameters from each of these units. These parameters are then indexed to a variety of environmental test conditions. This data set is then analyzed to gain insight into arcing behavior through the use of statistical tools.\(^10\)

This method has been applied to the analysis of peak arcing current, strike and stop phase angle and voltage, and arcing energy. For example, a review of arcing peak current has shown that the probability distribution function (PDF) of these data is described by a lognormal function, with the median value generally at 75 percent to 80 percent of short-circuit current. Importantly, this relationship is found to be true
regardless of the magnitude of short-circuit current (whether it is arcing occurring at 5A or 500A, series or parallel arcing, carbonized path or point contact arcing).

**ARC ENERGY DISTRIBUTION AND IGNITION THRESHOLD**

UL determined that the amount of energy needed to ignite non-metallic (NM) cable was characterized assuming that “ignition” was achieved if any observable discoloration or charring was present on the NM cable. Data determined that the threshold for igniting NM cable through arcing is approximately 2kJ.¹¹

*Figure 2. Cumulative CDF Fits From (left), Comparing Data From Samples Showing Ignition to Those That Did Not. Numbers Show Coordinates for 5 Percent Probability of Ignition and Point Where the CDFs Cross*

Importantly, the use of energy release in predicting material ignition was applied in setting pass/fail criteria for UL Standard 1699B, where it was determined through experiments that there is a 5 percent probability of burning through a 1/16 inch PV connector when 750 J is released.¹² This demonstrates another value of our New Science work. We are able to use data to determine and set objective test criteria, enabling standards to be based on science.
UL research indicates that both DC and AC systems show that power is not a significant variable with respect to ignition in most arcing situations of short duration, suggesting that thermal loss through convection or conduction is not significant for the arcing events under consideration.

**ARCING EVENT LENGTH**

UL found that the total length of an arcing event is dependent on the arcing current and type and gauge of cable used. The arcing event tends to be shorter at higher currents than at lower currents. Arcing events also tend to be longer when a solid conductor is used, in comparison to standard conductors, which result in shorter arcing events. While these observations may have been noted before, the UL work has quantified the effects of stranding and arc current on arcing event length.

UL has demonstrated through research and analysis that the probability of arcing continuing to occur at a given point in time after the arcing event starts can be characterized by an exponential decay function.

*Figure 3. Plot of the Probability of Arcing With Respect to Time and Short-Circuit Current. Time Zero Equals the Start of the Arcing Event*
UNIQUE CHARACTERISTICS OF CARBONIZED PATH AND POINT CONTACT ARCING

UL research in 2010 suggested that carbonized path and point contact arcing differentiate significantly only through a change in strike voltage. The carbonized path shows strike voltages over a given threshold value, while point contact evidences voltages at all levels. Subsequent research confirms this previous finding and found that the method of arcing itself can also have an influence on behavior. For example, the distribution of strike angle differs between the arcing methods described in UL Standard 1699, Sections 40.3 and 40.4. The strike angle distribution in Section 40.3 shows a higher median value (approximately 90 degrees) than the methods described in Section 40.4 (approximately 40 degrees). These two methods also show different arc event lengths, with Section 40.3 resulting in shorter arcing events than Section 40.4. In addition, UL research found a series contact resistance that tends to lower the peak current values for point contact arcing relative to carbonized path arcing, which is on the order of 30 mΩ.

LONGER TERM

UL is continuing to research and analyze electrical arcing. Several areas under additional review include quantifying the effect of arc gap and peak current, improved arc ignition modeling, spectral analysis and glow connection phenomena. These topics will likely be shared in future New Science journals.

IMPACT

UL’s commitment to Fire Safety is long-standing, and while arcing has historically been associated with fires and is not new, UL’s statistical approach is. Our innovative methodology has enabled us to predict arcing behavior, expected energy release, fire incidence and other areas where we are able to better prevent arcing incidences and better protect residents and firefighters. We have developed standardized tools and analysis methods, and have accumulated knowledge that enables us to problem solve more effectively and efficiently. Additionally, our expertise and research-based knowledge have allowed us to collaborate with the National Electrical Manufacturers Association (NEMA) to offer a free online program designed to teach effective and safe ways to install and troubleshoot issues with arc fault circuit interrupters (AFCIs). UL is also working with the National Electric Code Panel, IEEE and NFPA, using science to further advance understanding and prevention of electrical arcing.
WIRELESS CHARGING OF ELECTRIC VEHICLES

STATISTICALLY PREDICTING ELECTRICAL ARcing

ADVANCED COMPUTER MODELING

NEW DYNAMICS OF BASEMENT FIRES
EVALUATING FIRE DYNAMICS AND STRUCTURAL RESPONSE TO FIRE THROUGH COMPUTER MODELING

WHY ADVANCED COMPUTER MODELING MATTERS
By using advanced computer modeling, UL is able to effectively leverage physical and virtual testing. Physical testing in the study of fire is expensive, and thus, generally very few tests are run on a particular product. Also, physical testing can only provide data at discrete points. However, it is still very important to design and carry out physical tests, as they can be valuable in validating computer models. Once a computer model is validated, it can be run under a variety of different input parameters much more economically than physical testing.

CONTEXT
Under pressure from fast and furious product development cycles and more stringent fire standards, manufacturers that wait for physical testing to find out if their products will perform safely may suffer a competitive disadvantage. Add to this mix that several new technologies are being developed such as fire-resistant coatings and engineered composites, and the challenge is enormous. UL now has the expertise in applying advanced computer modeling to complement fire testing and help establish an efficient hybrid approach to advancing Fire Safety science, fire standards and product safety.

UL has been using these advanced engineering tools to create virtual models of some products in fire tests within the standards. With such models, insights into the behavior of products in the extreme environment of fire can be gained, and when validated, a model can be adjusted to more efficiently predict the outcome of multiple scenarios and product design variations.

UL has been using computer modeling related to the Fire Safety of products in several ways:

• The performance of building components and materials subjected to a fire environment using a coupled thermal-structural finite element solver (ANSYS).
• Computational fluid dynamics (CFD)-based fire modeling software to predict the performance of fire sprinklers including interaction with fire.18
• Modeling the thermal performance of spray-applied fire-resistant coatings on steel columns for a variety of column shapes and sizes and coating thicknesses.

In all these cases, modeling provides a data-rich output, which can be analyzed and visualized in multiple ways to help provide the necessary insight to understand Fire Safety risks.
To provide a better picture of how UL is using state-of-the-art computer modeling, two important and challenging examples of the fire performance of building components will be covered: (1) the behavior of steel fire doors subjected to the fire endurance test and (2) the behavior of engineered wood products in a fire environment.

Both examples were analyzed using the finite element analysis (FEA) methodology. To build and solve an FEA model requires specific information describing the material properties, boundary conditions, assembly geometry and constructional details, loadings and even some consideration of the possible failure mode(s).

**PREDICTING THE BEHAVIOR OF STEEL FIRE DOORS**

Fire doors within a building are meant to resist the spread of fire from one part of a structure to another, to enable more effective fire mitigation and safe egress of the occupants. As a means of evaluating fire resistance, fire door assemblies are tested according to standards such as UL 10B. To effectively and efficiently build a suitable finite element representation of a fire door assembly subjected to a fire exposure, it is prudent to assess the necessary amount of detail that should be captured. UL has studied fire door modeling over the years and has found a variety of design details that are critical to accurate predictions.

However, first UL identified key engineering assumptions, based on our long history of testing fire doors, which generally hold true and help guide the finite element analysis. These include:

- The wall and frame holding the fire door are rigid during the entirety of the test and so need not be modeled in detail.
- The thermal insulation does not provide any structural stiffness to the fire door assembly.
- The coupling between the thermal and structural responses is one-way during the early parts of the test as the structural response has a negligible effect on the thermal response.

Without describing the extensive fire door modeling work that UL has carried out in this area, we focus on one key aspect. For proper modeling of fire doors, the thermal contact resistance between mating steel components is critical. Generally steel fire doors consist of steel panels and steel stiffeners. These parts are structurally connected through welds. As the door deforms, these parts could deform differentially, changing the thermal resistance. Our research found that simply assuming that heat transfer occurs through the weld points would underestimate the heat transfer.
through the door and in turn affect the predicted structural results. Information about the thermal contact resistance and its changing nature is generally not known by the manufacturer. However, the model can show the effect of different thermal contact configurations and provide insight into design decisions that may improve the fire performance of the door.

THE FIRE PERFORMANCE OF WOOD BEAMS

This modeling work was part of a larger multi-year research plan to understand the fire performance of engineered wood, common in new residential dwellings versus traditional lumber that is typical of older homes. Despite the large amount of testing, a validated FEA model of wood beams that can predict the effect of different design changes would be very valuable in developing a strong technical basis for possible building code revisions and changes in firefighting tactics.

Unlike other building components such as masonry and brick, there are several specific challenges in predicting the response of wood-based structures to fires. The key challenge is that wood burns. The burning of wood leads to material degradation and decomposition through pyrolysis. Wood is also a complex composite of natural polymers and is generally anisotropic, heterogeneous and porous. The properties of wood are also affected by moisture content. And in a fire environment, any moisture contained within wood will evaporate and diffuse, altering material properties. Last, the failure mode of a wood-based building component would depend upon details of the construction, material imperfections, connections, etc. What’s more, all these material properties would need to be known over the temperature range that wood would reach in a fire environment.

Our modeling results were able to demonstrate quantitative agreement in trends seen during testing for both single beam and wood beam floor assembly tests. The key trend was that the traditional lumber beam lasted much longer than the engineered wood beam under similar fire and mechanical loading conditions. In addition, the model provides insight into parameters such as charring rate, which was found to compare favorably with the range of data in the published literature.

The FEA model and advanced analysis were able to predict the onset of instability where the deflection rate increased substantially. The model also revealed that for the engineered wood beams, the main failure path is the burnout of the web, thereby transferring load sharing to the top chord, as the lower chord — though mostly unburned — was then separated. For the traditional lumber rectangular section beam, the failure path mainly reduces cross section through three-sided heating and through a combination of weakened material properties and reduced cross section, which eventually fails to sustain the load.
UL continues to innovate using our expertise to offer a more comprehensive approach to Fire Safety. By using computer modeling and sophisticated analytical techniques, we are more effectively able to predict fire behavior, assess risk and provide insights that can lead to better design decisions.
Wireless Charging of Electric Vehicles
Statistically Predicting Electrical Arcing
Advanced Computer Modeling
New Dynamics of Basement Fires
WHY NEW DYNAMICS OF BASEMENT FIRES MATTER
In the real world, the fire service will never respond to two fires that are exactly the same. During all of our recent basement fire experiments, where the variables were systematically controlled, there were no reliable and repeatable warning signs of flooring collapse. Because the consequences of falling through a floor into a basement fire can be catastrophic, it is critical for firefighters to understand the hazards associated with different types of flooring products and systems to enhance operational procedures, protection methods and overall firefighter safety.24

CONTEXT
Basement fires are one of the most challenging and dangerous types of fires that firefighters face. They can find themselves in a position where they’re operating above a fire — in some cases without knowing it. Often the fire service has no idea how long the fire has been burning, the type of floor system exposed to the fire conditions, or the structural stability of the floor system, and there are little, if any, warning signs of collapse.25

In particular, basement fires that involve an unprotected wood floor assembly can pose a number of challenges to Fire Safety. Light-weight engineered floor systems provide architectural, economic and productivity benefits to the homeowner and the construction industry. However, under fire conditions, these light-weight engineered floor systems lead to greater risk of structural failure in a shorter time as a consequence of the reduced cross-sectional dimensions of the engineered products as compared to traditional dimensional lumber floor systems. So, despite the superior structural performance of these new products to traditional lumber construction under “normal” conditions, the trend reverses in a fire environment. This is highlighted by the increasing number of firefighter fatalities due to collapse of these engineered systems under fire conditions. The National Institute for Occupational Safety and Health (NIOSH) issued a report, Preventing Injuries and Deaths of Fire Fighters Due to Truss System Failures, highlighting the risks of injury and death that can occur during fire-fighting operations involving engineered floor truss systems.26

WHAT DID UL DO?
UL partnered with several research organizations, product manufacturers and fire service representatives to examine hazards associated with various types of residential flooring systems. Funding for this project was provided through the National Institute of Standards and Technology’s American Recovery and Reinvestment Act Grant Program. The main objective of this first-of-its-kind research was to improve Fire Safety by better understanding the response of residential flooring systems to fire.27
UL conducted five types (or series) of experiments to examine basement fires and collapse hazards posed to the fire service:

1. Floor Furnace Experiments: UL examined several different engineered floor systems and dimensional floor systems and different protection methods. We also altered the load to understand different stresses in the floor systems.

2. Heat Release Rate Experiments: Through these experiments, UL developed a repeatable fuel load that would be representative of fires that firefighters would find in actual basements.

3. Basement Field Experiments: In these field experiments, UL used fabricated basements to examine firefighter ventilation practices and how different types of floor systems performed under basement fire conditions.

4. Basement Lab Experiments: In these controlled experiments, UL replicated the same basement configuration as in the previous field experiments, but was able to control variables such as weather conditions, and wind conditions and study different types of floor systems and protection methods to examine the code implications of what firefighters could see in the field.

5. Full-Scale Field Experiments: UL was able to perform two full-scale collapse experiments, where we ignited the fire in the basement of an acquired residential structure and allowed it to spread naturally throughout the house.

There are 10 key tactical considerations that result from this comprehensive and innovative Fire Safety research that firefighters can use immediately to enable improved decision making at the fire scene:

1. Collapse times of all unprotected wood floor systems are within the operational time frame of the fire service regardless of response time. Specifically, engineered floor systems can collapse as early as 2 – 3 minutes after the structure becomes involved in the fire.

2. Size-up should include the location of the basement fire as well as the amount of ventilation. In these experiments, collapse always originated above the fire, and the more ventilation available the faster the time until floor collapse. When possible, the floor should be inspected from below prior to operating on top of it.
3. Signs of collapse vary by floor system:
   a. Dimensional lumber should be inspected for joist rupture or complete burn through.
   b. Engineered I-joists should be inspected for web burn through and separation from subflooring.
   c. Parallel Chord Trusses should be inspected for connection failure.
   d. Metal C-joists should be inspected for deformation and subfloor connection failure.

4. Sounding the floor for stability is not solely reliable and therefore should be combined with other precautionary tactics to increase safety.

5. Thermal Imaging Cameras (TICs) may help indicate that there is a basement fire when the fire condition is visible to the camera’s field of vision, but TICs cannot be used to assess structural integrity from the floor above.

6. Quickly descending the stairs to find relief at the bottom was not possible. Floor temperatures at the bottom of the basement stairs were often worse than temperatures at the top. This finding contradicts conventional wisdom about heat rising and the thought that cooler temperatures would be found at the bottom of the stairs.

7. Coordinating ventilation during fire suppression is extremely important. Ventilating the basement created a flow path up the stairs and out through the front door of the structure, almost doubling the speed of the hot gases and increasing temperatures dramatically.

8. Floor sag is a poor indicator of floor collapse. Any perceivable weakness is a late indicator that the floor system has already been damaged or completely compromised.

9. First-floor temperatures can be a poor indicator of fire conditions that exist below, especially when remote from the top of the stairs or the initial fire condition.

10. Hose lines should be available when opening up void spaces that contain areas of combustible construction.29

Well-designed fire tests not only help provide information on a particular scenario but should generate the detailed data needed to help validate computer models. The use of computer modeling in fire engineering is only growing, so it is vital that the limited expensive and large-scale fire tests that are conducted be designed with
The building and construction industry is continually introducing new engineered products that provide better structural stability, allow for faster construction and are more cost effective. Additionally, the increased market demand for environmentally sustainable products is driving engineered lumber products to further reduce material mass, which could potentially result in even greater concern for Fire Safety. The 10 key tactical considerations that resulted from UL’s comprehensive and innovative Fire Safety research enable firefighters to improve decision making on the scene when encountering these new materials. In addition, UL is helping advance the use of fire modeling tools that can have a significant impact on furthering insights into scenarios that firefighters must confront and on improving training materials for firefighters.

IMPACT

The building and construction industry is continually introducing new engineered products that provide better structural stability, allow for faster construction and are more cost effective. Additionally, the increased market demand for environmentally sustainable products is driving engineered lumber products to further reduce material mass, which could potentially result in even greater concern for Fire Safety. The 10 key tactical considerations that resulted from UL’s comprehensive and innovative Fire Safety research enable firefighters to improve decision making on the scene when encountering these new materials. In addition, UL is helping advance the use of fire modeling tools that can have a significant impact on furthering insights into scenarios that firefighters must confront and on improving training materials for firefighters.
NEW CHALLENGES. NEW RISKS. NEW SCIENCE.

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