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Assessing the Skin Abrasion Potential of Driver-Side Airbags

Technical Report

Matthew P. Reed
Lawrence W. Schneider

The University of Michigan
Transportation Research Institute
2901 Baxter Road
Ann Arbor, Michigan 48109-2150

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16. Abstract

Investigations of airbag deployments in the field have indicated that while airbags reduce the overall incidence and severity of injury to occupants in frontal collisions, certain minor injuries induced by the deploying airbag can occur. These include skin abrasions to the face, neck, hands, and forearms caused by interaction between the occupant and the deploying airbag. A study was conducted using human volunteers to investigate the airbag design and deployment factors that contribute to airbag-induced skin injury. As part of that study, a laboratory test procedure was developed to assess the skin-injury potential of driver-side airbags using a pressure-sensitive film and a specially designed test fixture. The airbag is mounted in the fixture and deployed so that the airbag fabric strikes the pressure-sensitive film. The pressure distribution on the target surface is determined by digital image analysis of the film and compared to levels of surface pressure corresponding to varying levels of injury severity in tests with human subjects. The information is used to predict the likelihood and severity of skin abrasion. This report describes the fixture, test procedures, and analysis techniques used to assess the abrasion potential of airbags.

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CONTENTS

1.0 INTRODUCTION

Investigations of airbag deployments in the field have indicated that while airbags reduce the overall incidence and severity of injury to occupants in frontal collisions, certain minor injuries induced by the deploying airbag can occur. These include thermal burns to the hands and forearms due to the hot gases used to inflate the airbag, and skin abrasions to the face and neck caused by interaction between the occupant and the deploying airbag. To address the causes of the latter type of injury, a study was conducted at UMTRI using deployments into the anterior tibia regions of human volunteers to investigate the airbag design and deployment factors that contribute to airbag-induced skin injury (Reed and Schneider 1992). The research resulted in the development of laboratory techniques for assessing the mechanical skin injury potential of driver-side airbags. These techniques are presented in this report.

The term "abrasion" used in this report refers to mechanical trauma to the skin affecting the epidermis and dermis, including injuries caused by oblique or grazing impacts (scrapes) and imprint abrasions caused by impacts approximately normal to the skin surface. An important finding from this study is that the primary determinant of the occurrence and severity of abrasion is the magnitude of the surface pressure impulse generated during impact with the skin of airbag fabric moving at very high velocities normal to the skin. Based on this finding, a laboratory technique that measures the peak pressure on a target surface has been developed to provide a quantitative measure of the skin injury potential of an airbag deployment.

The procedure consists of conducting static deployments of the airbag into a cylindrical target surface located specified distances and orientations relative to the airbag module. Pressure-sensitive film attached to the target surface records the peak pressure on the surface from the impact of the deploying airbag. Digital image analysis is then used to produce a quantitative description of the peak surface pressures. The extent and severity of injury that would be expected to result from the airbag interacting with human skin can be predicted by reference to human tolerance guidelines developed in the UMTRI study. Additional information on the airbag kinematics associated with the potentially injury-producing events is obtained through analysis of high-speed film taken of the static deployment.

Information obtained through use of this test procedure can be used to reduce the abrasion potential of airbag systems, particularly by comparing the results obtained with different airbag configurations (*e.g.*, different inflators or airbag fold techniques). However, because the injury thresholds incorporated into the procedure are derived from a limited number of tests with human subjects, final evaluation of an airbag configuration may require testing with human volunteers (Reed and Schneider 1992).

2.0 TEST FIXTURE FOR STATIC DEPLOYMENT TESTING

The test fixture illustrated in Figure 1 and Attachment 1 has been developed for testing driver-side airbags. The rectangular frame is fabricated from 38-mm (1.5-in) square-section Telespar tubing. In the UMTRI laboratory the fixture is clamped to an elevated test buck that facilitates access to the fixture. A standard steering wheel is mounted inside one end of the frame. A cylindrical target surface comprised of a 102-mm-diameter, 500-mm-long polyvinyl-chloride (PVC) pipe is oriented vertically in the plane of the frame. The horizontal distance from the steering wheel and airbag module to the target surface is adjusted by threaded rods. Because of the box-frame design of the fixture, the forces of the airbag deployment and interaction with the target surface are sustained within the frame, so the test fixture supports are not required to carry large loads.

The fixture allows the steering wheel to be rotated so that the airbag module can be deployed from different orientations relative to the surface of the target cylinder (see Section 5). The dimensioned drawing of the fixture (Attachment 1) shows the center of the steering wheel offset 25 mm (1 in) from the plane of the fixture to place the center of the airbag module on the plane of the fixture frame. This adjustment is necessary when using a steering wheel with an eccentrically mounted airbag. The configuration shown in the drawing is appropriate for a steering wheel with an airbag mounted below the center of the wheel (with the wheel in a neutral position) when the steering wheel is turned ninety degrees clockwise for testing.

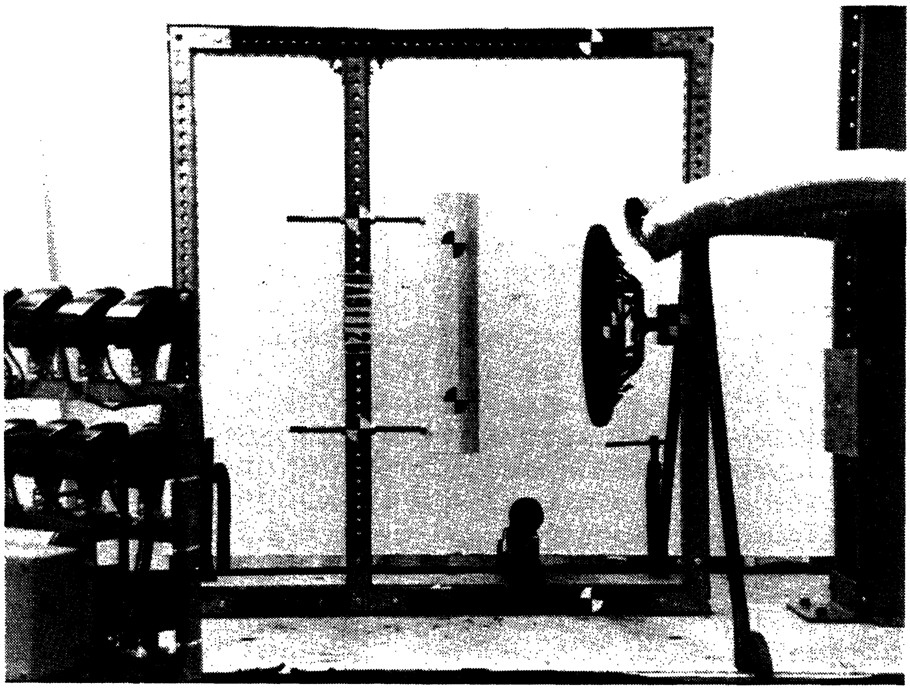

Figure 1. Test fixture for static laboratory deployments.

3.0 LABORATORY FACILITIES

The nature of airbag testing necessitates certain additional test equipment. Proper ventilation is required to exhaust the products of combustion from the airbag inflator. A ceiling-mounted blower in the UMTRI lab draws approximately 57 m^3/min (2000 ft^3/min) through two 150-mm (6-in) ducts situated near the airbag vents. Additional ventilation is provided after testing by opening a damper above the test fixture to exhaust room air.

High-speed film documentation of the deployment at 3000 frames per second or greater is necessary to study the airbag kinematics. The UMTRI lab uses a NAC E-10 camera running at 3000 or 6000 frames per second. To accommodate the high frame rate, intensive lighting is used to raise the illumination of the target area to above 172 000 lux (16 000 ft-cd). Because of the high heat generated by the lighting, the lights are electronically sequenced and powered only when needed. An eight-channel electronic sequencer controls the timing of test events, activating the lighting, high-speed camera, strobe, and airbag at the appropriate times.

4.0 CALIBRATION AND MEASUREMENT PROCEDURES

4.1 Abrasion Mechanisms

Research at UMTRI has demonstrated that abrasions caused by airbag deployments are due primarily to high surface pressures on the skin caused by high-speed impact of the airbag fabric with the skin. This contrasts with the more intuitive hypothesis regarding airbag-induced abrasions that the injuries are due to shear-type loading (scraping) of the skin by airbag fabric moving laterally against the skin. UMTRI data indicate that, during injury events, an area of airbag fabric typically impacts the skin at speeds between 60 and 180 m/s. The tissue in that area can experience peak surface pressures in excess of 200 kg/cm^2 (2800 psi), causing tissue damage in the epidermis and dermis. Although lateral movement of the airbag fabric against the skin (scraping) can occur and may contribute to the severity of injury, this scraping action is generally not sufficient to cause injury to the dermis in the absence of high surface pressure between the fabric and the skin. However, high surface pressure is sufficient to cause injury even in the absence of scraping (Reed and Schneider 1992).

4.2 Prescale Film

Measurements of peak surface pressure on a rigid target surface during an airbag deployment have been found to be effective for predicting human skin injury with similar deployment configurations. Fuji Prescale film is a pressure-sensitive material that shows a color change from white to red corresponding to peak pressure. The plastic film surface is evenly coated with microcapsules containing a color-forming material that reacts with a surrounding color developer when the microcapsules are ruptured. The Fuji system is designed to provide an even and reproducible graduated color change over a range of applied pressures. When exposed to a time-varying pressure, the film indicates the highest pressure applied. Although the material is available in a range of sensitivities and one- and two-sheet designs, the single-sheet, medium sensitivity (MS) film is most appropriate for this application. This film has a useful pressure range from about 100 to 500 kg/cm^2 (1400 to 7000 psi).

4.3 Calibration

Since the film is slightly sensitive to the duration of the applied pressure, a calibration procedure was developed using a pressure pulse duration more similar to the one to be measured than the calibration supplied by Fuji. Figure 2 and Attachment 2 show the calibration device used at UMTRI. A sample of film is held between a film platform and a

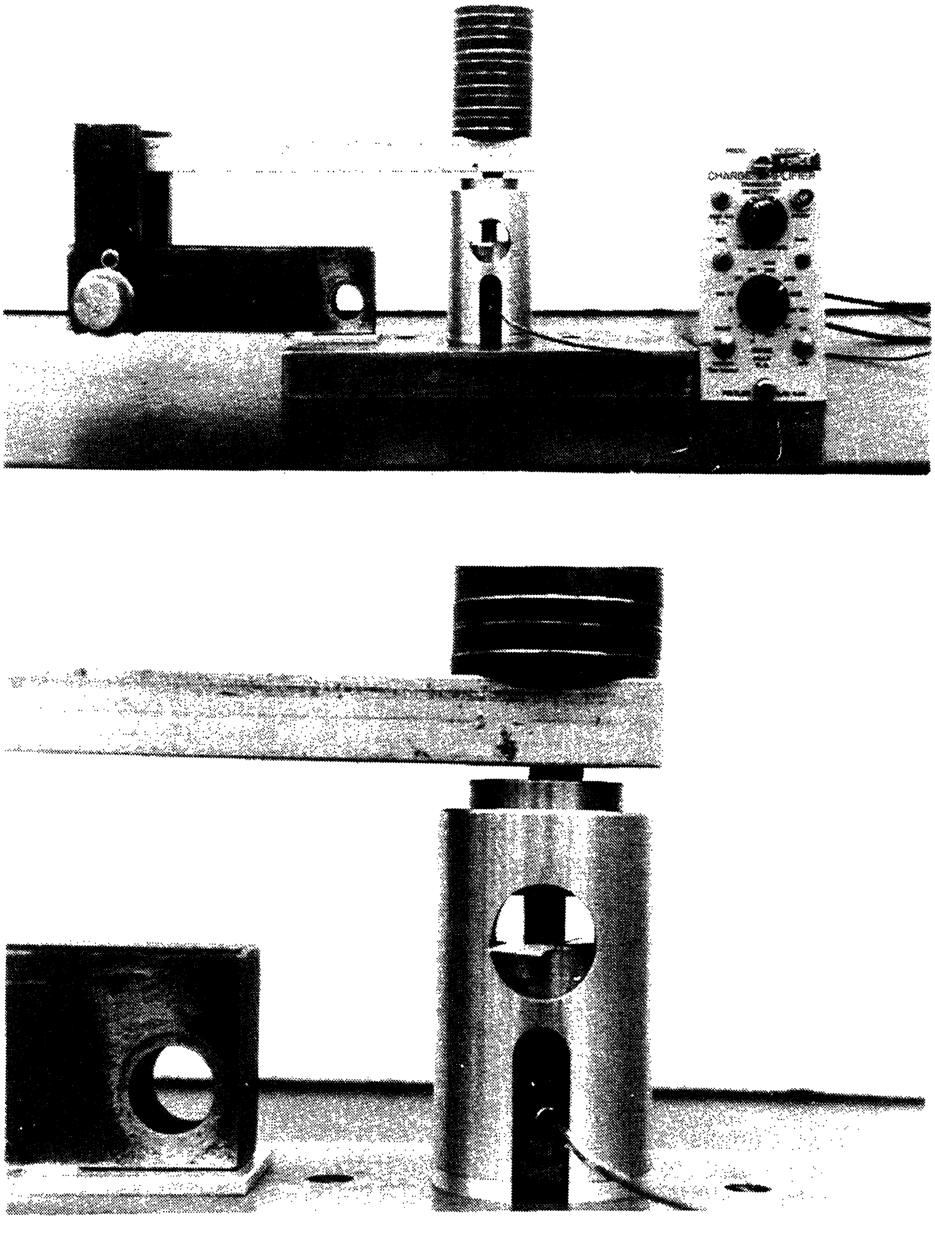

Figure 2. Prescale film calibration device.

10-mm-diameter post. Both surfaces are polished steel. Pressure pulses of approximately 1-ms duration (at the base of the pulse) are produced by dropping the weighted arm onto the calibrator assembly. A 5-mm-diameter piece of synthetic foam rubber at the point of impact provides control over the width of the pulse. The pressure level applied to the film is measured by a piezo-electric load cell located beneath the film platform and the signal is recorded with a digital storage oscilloscope.

Application of different pressure levels produces circular dots on the film ranging from light pink to bright red corresponding to low and high peak pressures, respectively (Figure 3). To relate the color density to the magnitude of the applied pressure, the film samples are digitized on an 8-bit, 600-dpi (dots per inch) flatbed scanner in greyscale. This method assigns a value from 0 (lightest) to 255 (darkest) for each pixel of the image. A pixel is the smallest element of a digital image. At 600 dpi, one pixel represents an area 0.0017 x 0.0017 inches or 0.04 x 0.04 mm. The pixel values for each calibration dot are averaged over an area slightly smaller than the dot to eliminate edge effects. These mean pixel values are plotted versus the measured peak pressure for each trial and a curve fit to the data.

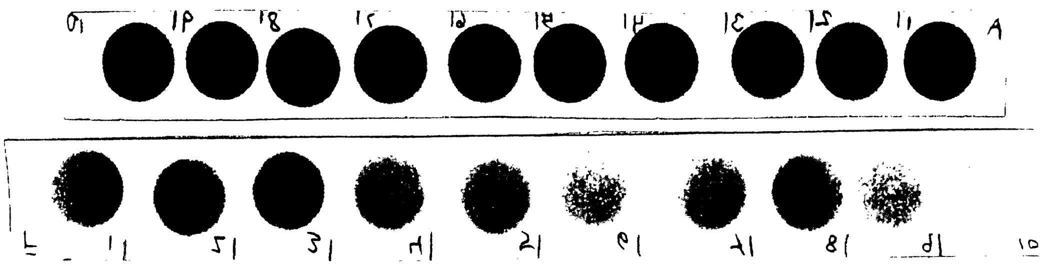

Figure 3. Prescale images produced by calibration device.

Figure 4 shows a calibration curve for this material obtained using a Microtek 600 ZS scanner and Image 1.41 analysis software on a Macintosh IIci microcomputer. Since analysis using other scanner hardware would likely produce a slightly different curve, these data are provided only for purposes of illustration. A new calibration curve should be developed for each scanner used in testing.

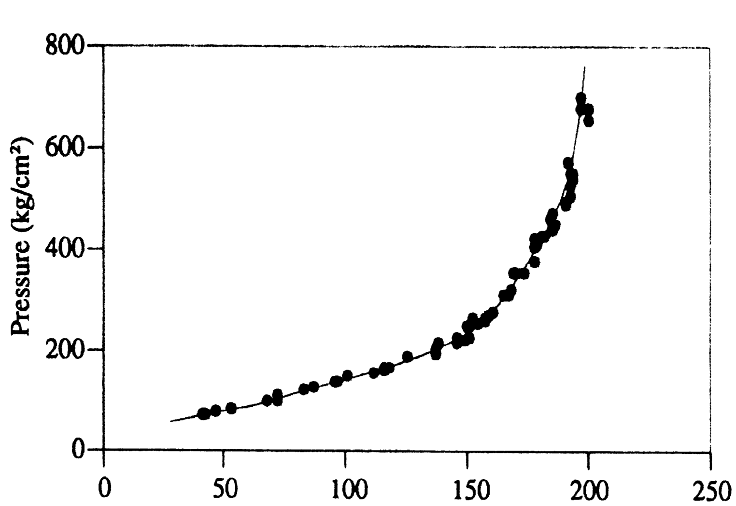

Figure 4. Calibration curve for Prescale film using 1-ms duration pressure pulses.

4.4 Conditions and Limitations of Prescale Film Measurements

There are some important limitations to the accuracy and precision of the Prescale film. Because the color change is produced by a chemical reaction on the surface of the film, the response of the film is affected by temperature and humidity, particularly the latter. A controlled laboratory environment is important and calibration trials should be carried out in the same laboratory as the airbag tests. The color-producing chemical reaction is also time dependent, so scanning of Prescale images should be conducted a uniform interval of time after exposure. The precision of the Prescale film is rated by Fuji as ±10 % although better results are obtainable if the temperature, humidity, and scanning interval are carefully controlled. The accuracy is dependent on the suitability and accuracy of the calibration procedure. The load cell used for the UMTRI calibrations was calibrated in a static mode and checked dynamically.

The most significant limitation of this measurement technique is the unknown nature of the pressure pulse produced by impact of the airbag fabric with the Prescale film during testing. Testing with more conventional sensors has indicated that the pulse is less than one millisecond in duration when the airbag is deployed into a rigid aluminum plate. Discrepancies between the duration of the calibration pulse and duration of the impact of the airbag with the film will produce errors in the peak surface pressure measurement. If the impact event is of shorter duration than the calibration pulse, the Prescale film analysis will produce peak pressure measurements less than the actual values.

Potential inaccuracies due to deficiencies in the calibration of the film are not of primary importance because of the nature of the testing. This test procedure is not intended to measure accurately the surface pressure levels that would be experienced by a human subject exposed to the airbag deployment. Rather, the procedure is designed to determine if the impacts of the airbag fabric are sufficiently severe to cause human skin injury. As such, the peak surface pressures on the test fixture are compared to other test fixture data from airbag configurations for which human subject injury data are available. A threshold pressure level for this test procedure has thus been determined above which human skin injury is considered likely for an identical deployment configuration (see Section 6).

5.0 TEST METHODS

An assessment of the injury potential of a particular airbag module requires a series of tests. The procedure may be separated into two phases: description of kinematics and measurement of impact severity.

5.1 Description of Kinematics

Airbag deployment kinematics are influenced by a number of design factors, including the airbag fold technique, the resistance of the module cover to rupture, the characteristics of the inflator, and the presence of a tether. Changes in the deployment kinematics alter the potential fabric-skin impact locations and velocities. Tests with the Prescale film should be configured to measure target surface pressures at all high-fabric-velocity locations in the deployment envelope. To accomplish this, knowledge of the deployment kinematics is required.

The deployment kinematics are observed through analysis of high-speed films taken from the side of the test fixture. Different camera angles are effectively achieved by changing the rotation angle of the steering wheel in different tests. With most fold techniques, two orthogonal views are sufficient to describe the airbag motion (*e.g.*, with the steering wheel in the neutral position and rotated ninety degrees). Frame-by-frame analysis of the film is used to determine the approximate velocity of different sections of the airbag fabric. With many airbag fold techniques, certain fabric sections move much more rapidly than adjacent sections during the early phases of the deployment. As noted above, this high-velocity airbag fabric has the potential to produce skin injury.

Deployments for the purposes of kinematic evaluation can be conducted both with and without the target cylinder. Deployments without the target cylinder are useful for determining the range of the deployment envelope and to examine the unobstructed motion of the airbag. With the target cylinder in place, the airbag interaction with the surface can be observed. The latter type of test is particularly useful for determining the portion of the airbag fabric that is most likely to cause an injury at a particular point in the deployment envelope.

5.2 Measurement of Impact Severity

After identification of the regions of the airbag deployment envelope through which airbag fabric moves at high velocity, the test fixture is adjusted to bring the target surface of the cylinder into the appropriate relationship relative to the steering wheel to measure the pressures produced by fabric impact. The steering wheel may be rotated to bring a fabric motion of interest into the plane of the fixture (directing the primary fabric motion along the longitudinal axis of the cylinder) and the target surface may be moved horizontally to change the distance from the target surface to the airbag module. Additionally, the steering wheel may be offset laterally to change the relationship between the center of the airbag module and the plane of the test fixture frame, as shown in Attachment 1.

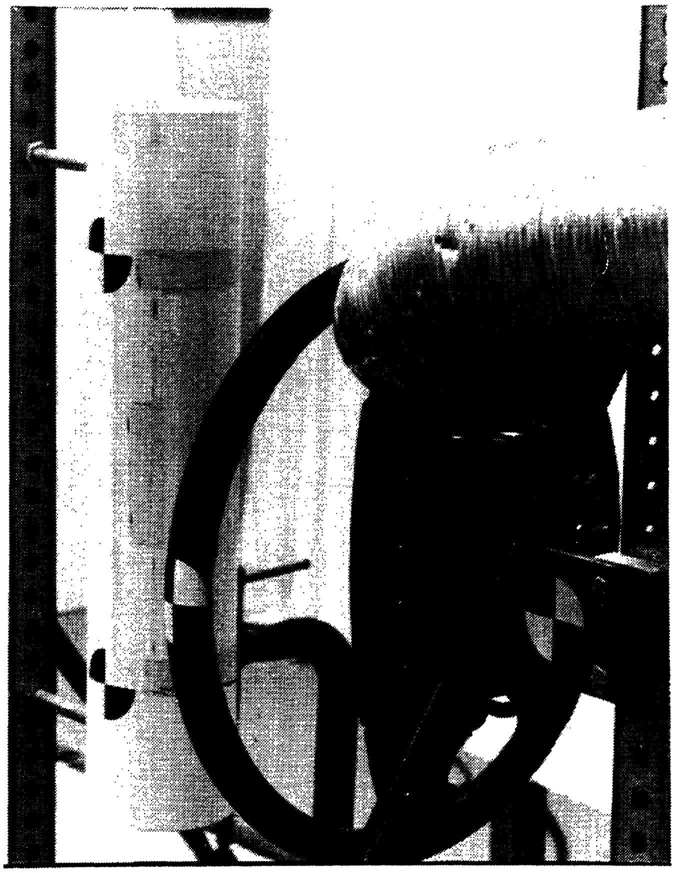

Figure 5. Prescale film attached to the target cylinder with adhesive tape.

Deployments are then carried out with the Prescale film on the target surface. The film is supplied by Fuji in 170-mm-wide rolls. A rectangular piece of film approximately 100-mm wide and 170-mm long is cut from the roll. Although the film is pressure sensitive, reasonable care will prevent damage to the film. The film is placed on the surface of the cylinder with the side coated with microcapsules against the cylinder surface. The plastic backing of the film protects the microcapsules from being scraped by the airbag fabric while allowing response to pressure. The film is held in place at the edges with adhesive tape (Figure 5).

After the deployment test, the color image on the film depicts the pattern of peak pressure produced on the target surface by impact of the airbag fabric. The shape of the pattern can indicate which section of airbag fabric is responsible for an area of high pressure. For instance, in impacts involving an airbag seam, the pattern of stitching is often clearly visible in the Prescale image.

Figure 6 shows two Prescale images from tests with the target cylinder located 225 mm from the airbag module cover. Test configurations A and B in the figure correspond to different airbag module configurations. The image from test configuration B contains areas of darker color, corresponding to greater surface pressure on the target cylinder. This is qualitative evidence that airbag configuration B is more likely to injure human skin under these test conditions.

Test Configuration A   Test Configuration B

Figure 6. Prescale images from two tests with Prescale film.

6.0 ANALYSIS OF PRESCALE IMAGES

After a test, the exposed Prescale film is removed from the cylinder and scanned using the same equipment and software that was used in the Prescale calibration. The digital scan of the image represents the distribution of image density as pixel values. These pixel values are expressed as pressure levels by reference to the calibration curve for the Prescale film. A filtering algorithm can be used to display on the computer screen only the areas of the image for which the measured pressure level exceeds a particular threshold. The threshold can be adjusted to observe the surface areas that correspond to varying levels of skin injury.

Figure 7 shows contour plots of the pressure values calculated for the Prescale images in Figure 6. The pixel values have been converted to pressure levels by reference to the calibration curve (see Section 4.3). Darker areas in Figure 7 correspond to areas of higher peak surface pressure.

Experiments with human volunteers and a limited number of airbag deployment configurations indicate that abrasion can be expected for impacts that produce surface pressure levels exceeding 175 kg/cm^2 using the procedure described above. The actual injury threshold will vary among subjects and may be affected by the characteristics of the impacting fabric, *e.g.*, the presence of a seam or fold. Higher surface pressures indicate the likelihood of more severe injury. In Figure 7, the threshold value is exceeded in an arc-shaped area of the image from test configuration B. Injury would be expected in this area for an identically configured test with human skin.

Figure 8 shows a photograph of a male volunteer's leg 15 minutes after a deployment with the same airbag module used in test configuration B. The volunteer's leg was placed in the same position relative to the airbag module as was the test fixture target surface. The location, shape, and size of the abrasion evident in Figure 8 are consistent with the evaluation of surface pressure measurements made using the quantitative test procedure.

Evidence of low impact pressures with this procedure indicates that the potential for skin injury is low. However, it is possible that skin injury could occur in situations for which the test procedure does not indicate that injury is likely because of the limitations of the data used to derive the 175-kg/cm^2 threshold value. Human-volunteer tests were conducted with young male subjects whose skin may not be representative of the driving population. Additionally, facial skin may have a different injury threshold for this exposure than tibia skin. However, design decisions based on the results of these procedures will reduce the severity of abrasion injury even if the potential for occurrence is not eliminated.

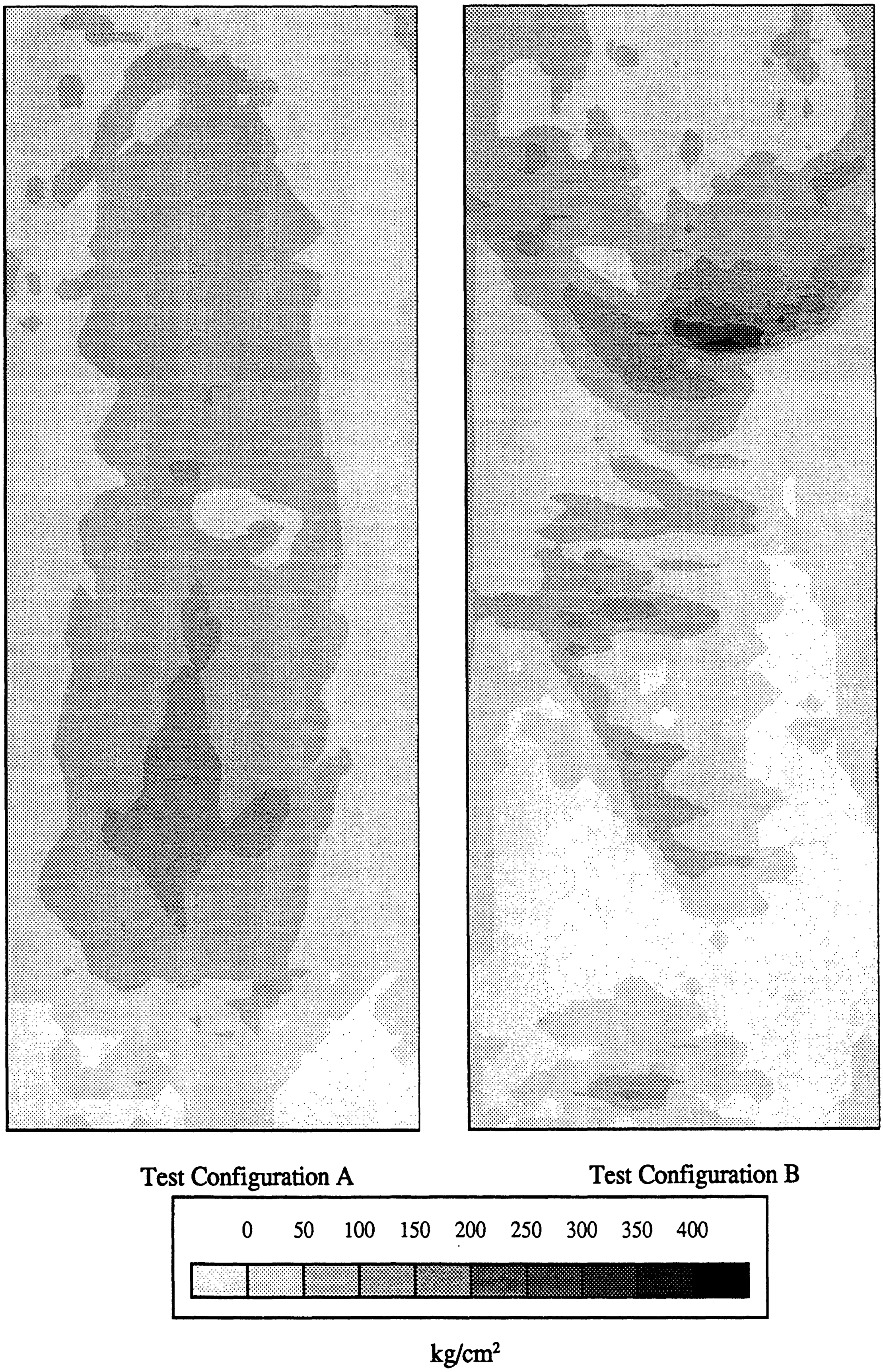

Figure 7. Contour plots of the pressure levels calculated from the Prescale images in Figure 6.

Figure 8. Deployment with human volunteer using test configuration B, 15 minutes post-test.

7.0 INJURY REDUCTION GUIDELINES

The test procedure described in this report can be used as a tool to reduce the potential for airbag-induced skin injuries. Changes in airbag fold techniques, module cover design, airbag fabric, inflator capacity, and other design and deployment factors can be evaluated using the procedure. The primary technique of injury reduction suggested by this procedure is the reduction of airbag fabric velocity during the deployment.

Since high-speed impacts of the airbag fabric with the skin are largely responsible for skin injury, the design strategy to reduce injury potential should be to decrease the incidence of high-speed fabric motion throughout the deployment envelope. This can be accomplished by a number of means, including reducing the capacity of the airbag inflator and changing the airbag fold technique. Further research will be necessary to determine the most effective means of reducing airbag abrasion potential.

REFERENCE

Reed, M.P. and Schneider, L.W. (1992) *Airbag-Induced Skin Abrasions: Design Factors and Injury Mechanisms*. Final Report No. UMTRI-92-7. University of Michigan Transportation Research Institute, Ann Arbor.

ATTACHMENT 1

Engineering Drawing of Airbag Test Fixture

ATTACHMENT 2

Engineering Drawing of Calibration Device