NATIONAL TRANSPORTATION SAFETY BOARD

Office of Research and Engineering
Materials Laboratory Division
Washington, D.C. 20594

December 22, 2004

MATERIALS LABORATORY FACTUAL REPORT Report No. 04-138

A. ACCIDENT

Place	:	Port Richey, Florida
Date	:	October 17, 2004
Vehicle	:	Express Shuttle II
NTSB No.	:	DCA05MM002
Investigator	:	Brian Curtis, MS-10

B. COMPONENTS EXAMINED

Fuel injection lines and clamp from the starboard engine.

C. DETAILS OF THE EXAMINATION

An overall view of the submitted fuel injection lines and clamps is shown in figure 1. Each fuel injection line was a 0.25-inch outer diameter tube connected to the fuel pump manifold at one end and to each of the eight engine cylinders at the other end. For this examination, the fuel injection lines were numbered according to the cylinder number to which the line was attached. The cylinders were numbered from the forward port number 1 to the aft starboard number 8. Odd numbered cylinders 1 to 7 were located on the port side of the engine. Even numbered cylinders 2 to 8 were located on the starboard side of the engine. As-received, fuel injection line number 5 was fractured at the pump manifold attachment location.

A total of nine line-to-line clamps were connected to various fuel injection lines. The clamps are shown lettered “A” to “I” in figure 1. Fuel injection line number 5 was not clamped at any location along its 38-inch length. One loose (unattached) clamp shown in figure 1 was found on-scene on the starboard engine block. The loose clamp was recovered in the unscrewed position with the end of the attachment screw shank located flush to the clamping plate surface.

Also, when examined on-scene, none of the fuel injection lines were found clamped to the engine block. Once the pump manifold and cylinder attachment locations were detached from the engine on-scene, the entire fuel injection line assembly as shown in figure 1 was free to separate from the engine.

A group examination of the fuel injection lines shown in figure 1 was conducted on November 30, 2004 in the Safety Board's Materials Laboratory. Representatives from Caterpillar, Inc. and for Ring Power Corporation participated in the group examination. The fuel injection lines and clamps had both loose and adherent oxides on their surfaces, consistent with exposure to heat and fire and subsequent extinguishing media. The upper and lower sides of the fracture surfaces on fuel injection line number 5 were covered in black to orange-colored oxide but having no specific pattern, similar to other exposed surfaces.

A closer view of fuel injection line number 5 at the fracture location is shown in figure 2. The fracture occurred at the upper edge of the ferrule for attaching the fuel injection line to the fuel pump manifold. The fracture was relatively flat and perpendicular to the longitudinal axis with no macroscopic deformation adjacent to the fracture, features consistent with a macroscopically brittle fracture mechanism.

The upper fracture surface was cleaned with soap water and a brush followed by cleaning with a deoxidizer. Views of the cleaned and deoxidized fracture surface are shown in figures 3 and 4. Some areas of oxide remained, visible as orange areas in figure 3.

The fracture surface had relatively flat fracture features on offset planes consistent with fatigue fracture across approximately 95 percent of the fracture surface. Dashed lines in figure 4 indicate approximate fatigue boundaries, and unlabeled arrows indicate local directions of fatigue propagation. Most of the fatigue region had features that emanated from a single origin area on the port side of the fuel injection line, propagating around the center of the tube and forming a ratchet mark[1] on the opposite side of the center hole as indicated in figure 4. The remainder of the fatigue region emanated from multiple origins around more than half the circumference on the starboard side. Many ratchet marks were observed around the circumference, and several of these ratchet marks are indicated in figure 4.

The outer diameter surface of fuel injection line number 5 was examined adjacent to the fracture. No evidence of crimping damage from the ferrule was observed.

An area of wear was observed corresponding to contact between lines 1 and 3, as shown in figure 5. At the location with the greatest reduction in cross-section, approximately 0.055 inch of material was removed from line 1 and 0.042 inch from line 3.

The location of each of the nine clamps was measured, and the results are shown in table 1. The locations of clamps "A" to "C" and "F" to "I" were measured as distances aft of the forwardmost fuel pump manifold attachment locations (1m and 4m in figure 1). The locations of clamps "D" and "E" were measured as distances starboard of a line

[1] A ratchet mark is a small step in the fracture surface formed when two adjacent fatigue cracks propagate on slightly offset planes. Although ratchet marks are typically associated with fatigue cracks originating on different planes, the ratchet mark shown adjacent to the center hole in figure 4 resulted from an intersection of fatigue crack fronts on slightly different planes after propagating around the center hole.

extrapolated from the port fuel pump manifold attachment locations (1m, 5m, 6m, and 8m in figure 1).

Table 1. Clamp Locations

Clamp Letter	Fuel Injection Lines Clamped	Clamp Location* (inch)	Reference Lines*
A	1, 7	15.1	Forward (1m, 4m)
B	1, 3	8.5	Forward (1m, 4m)
C	3, 6	6.8	Forward (1m, 4m)
D	6, 7	1.1	Port (1m, 5m, 6m, and 8m)
E	3, 8	8.5	Port (1m, 5m, 6m, and 8m)
F	4, 8	18.4	Forward (1m, 4m)
G	4, 6, 8	16.3	Forward (1m, 4m)
H	2, 8	14.3	Forward (1m, 4m)
I	2, 4	4.1	Forward (1m, 4m)

*Clamp location is the distance from the reference line defined by either the forward or the port fuel pump manifold attachment locations.

Clamp “B” was loosened and removed during the materials laboratory examination. The fuel injection line surfaces under the clamp were oxidized and had an appearance similar to that of the remainder of the lines.

Caterpillar, Inc. supplied the Safety Board a copy of the *Service Manual SENR5520* for 3408 and 3412 High Performance Marine Engines. On page 5 of the Specifications Section SENR5516-06 dated November 2004, an overhead view of a typical example of fuel injection lines on a 3408 engine was shown, but clamp locations were not specified. On the next page, a warning stated in bold type, “Be sure the fuel injection line clamps are installed in the correct location. Incorrectly installed clamps may allow the fuel injection lines to vibrate and become damaged. The damaged lines may leak and cause a fire.” On pages 95 and 96 of the Disassembly and Assembly section SENR5534-02 dated June 2003, the fuel injection lines are addressed in a segment titled, “Remove and Install Fuel Injection Lines”. In the procedures described in this segment, the fuel injection lines are removed and installed as a unit. A note at the end of this segment stated, “If it is necessary to loosen any of the fuel injection line clamps, retorque the screws to 2.26 N•m (20 lb in).” No procedure for removing or installing individual fuel injection lines was provided in this segment.

An area of fuel injection line number 5 near its center of gravity was sanded with 600-grit paper to remove the oxide, and hardness was measured. The hardness was 75.0 HRB (including a correction for the cylindrical surface). According to the representative from Caterpillar, Inc., the hardness was within the specified range for the fuel injection line.

Matthew R. Fox
Senior Materials Engineer

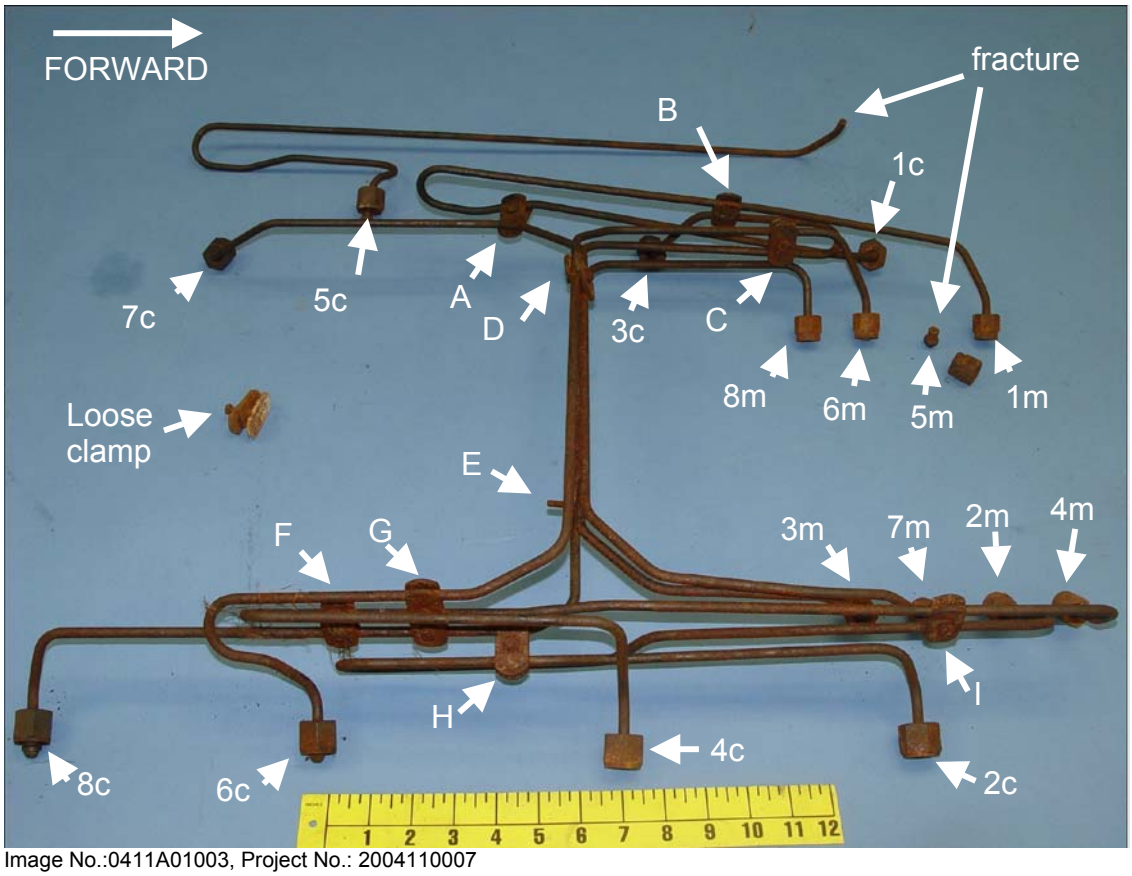

Image No.:0411A01003, Project No.: 2004110007

Figure 1. Overall view of the submitted fuel injection lines from the starboard engine as viewed looking from above with the starboard side in the foreground. Lines were numbered according to the cylinder to which they were connected. The ends of each line are labeled in the figure with the line number followed by a letter, where “c” indicates the cylinder end and “m” indicates the pump manifold end. Clamps are lettered “A” to “I” from aft to forward and from port to starboard.

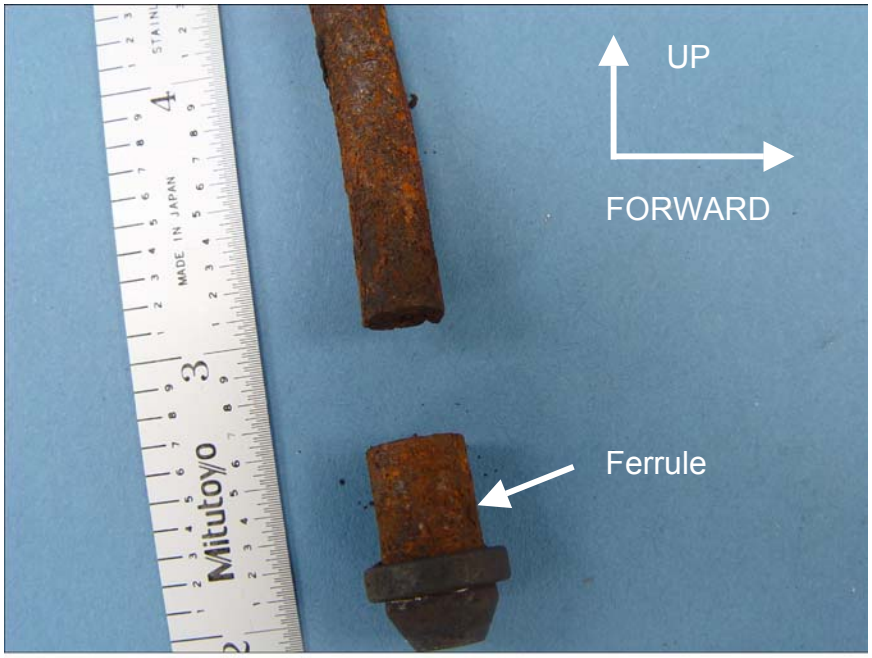

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Figure 2. Close view of the fracture area in line 5.

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Figure 3. Close view of the upper fracture surface in line 5 after cleaning with a deoxidizer. Some oxide remained on the surface, appearing orange in the figure. The fracture surface had fatigue features labeled in detail in figure 4.

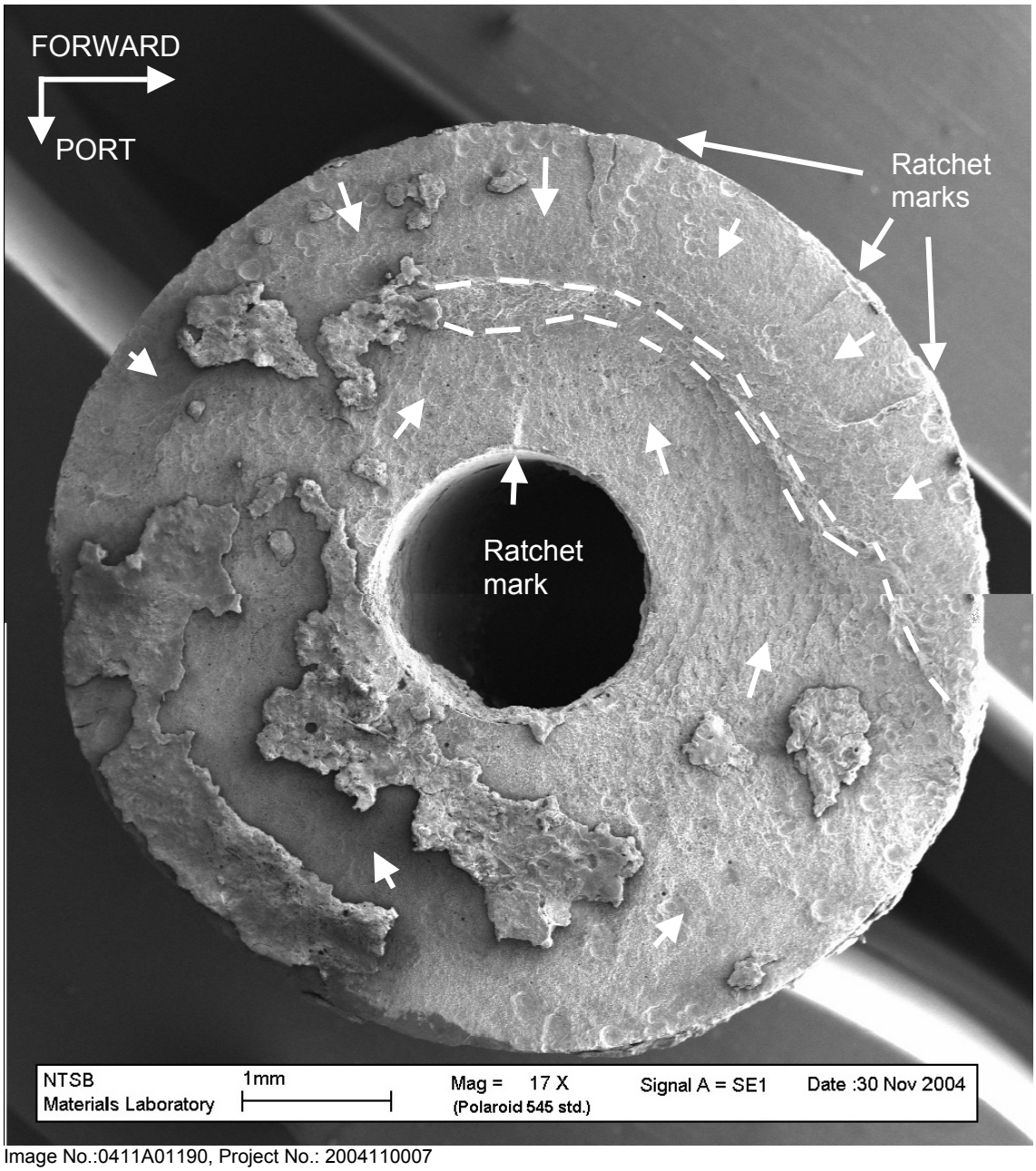

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Figure 4. SEM view of the fracture surface shown in figure 3. Dashed lines indicate approximate fatigue boundaries, and unlabeled arrows indicate local approximate fatigue propagation directions.

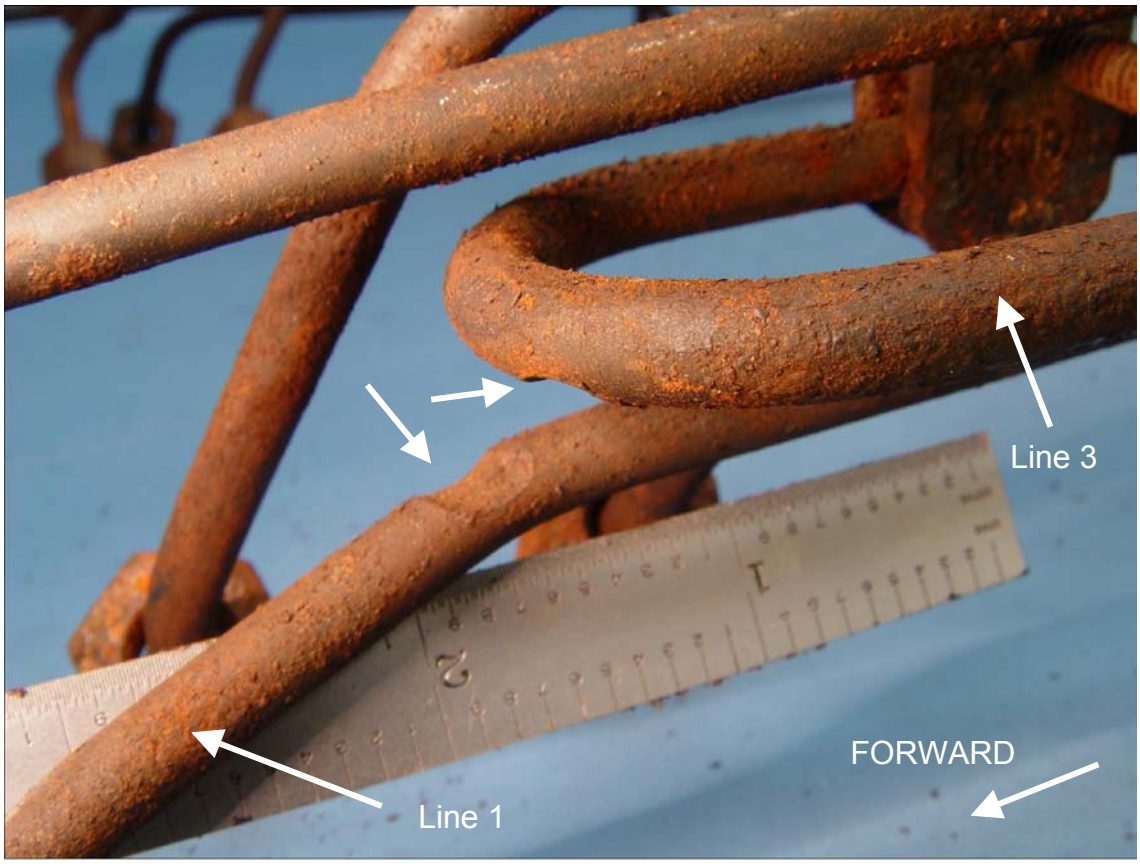

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Figure 5. View of wear as indicated by unlabeled arrows corresponding to contact between lines 1 and 3.