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F-117A Accident during Air Show Flyover Caused by Omission of Fasteners in Wing-support Structure

—

Bart J. Crotty
Aviation Consultant

On Sept. 14, 1997, the pilot of a Lockheed Martin F-117A felt an abnormal vibration when he initiated a climb during a flyover at 700 feet and 380 knots at an air show at Martin State Airport near Baltimore, Maryland, U.S. The U.S. Air Force stealth fighter then abruptly rolled to the left and pitched nose-up.

A large section of the left wing separated from the airplane and struck the ground between the runway and a taxiway. The nose section also separated from the airplane. The pilot ejected, and the airplane descended and struck the ground in a residential area.

The airplane was destroyed, and three houses were damaged by fire. The pilot sustained minor injuries. The Air Force said that no one on the ground was seriously injured; news media reports said that 12 people suffered minor injuries.

The Air Force said, in its investigation report, that the accident was caused by the omission of four fasteners, which resulted in failure of the brackets that attach a wing-support structure to ribs in the left wing.

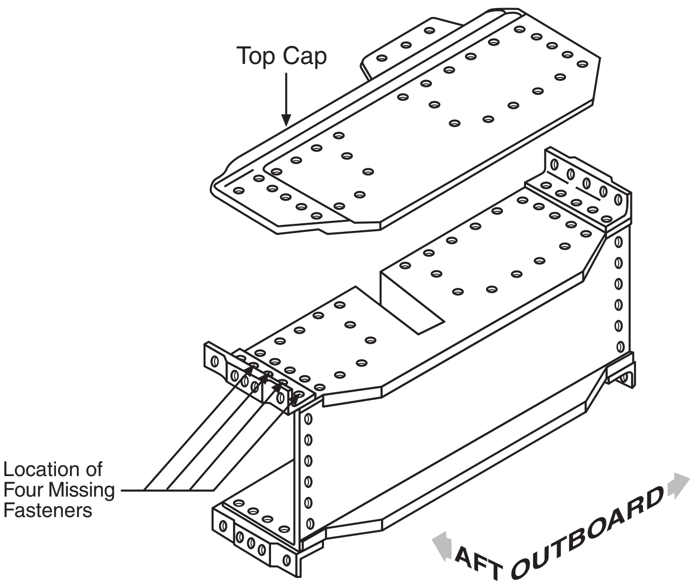
The aluminum wing-support structure, informally called a Brooklyn Bridge, measures 18 inches by 5 inches by 5 inches (45.7 centimeters by 12.7 centimeters by 12.7 centimeters). The structure spans the outboard-elevon integrated-servo-actuator (ISA) bay. The structure braces the wing and serves as a platform for attachment of the outboard-elevon ISA. (An elevon is a primary control surface that combines the functions of an aileron and an elevator.)

Figure 1 shows the wing-support structure. Figure 2, page 3 shows the location of the wing-support structure.

The Air Force said that four Hi-Lok fasteners (bolts) were omitted from one of the support structure's attachment brackets. Omission of the fasteners resulted in reduced structural rigidity of the left wing and allowed the support structure and the outboard-elevon ISA to move within the outboard-elevon ISA bay. This allowed uncommanded movements of the elevon to begin as the airplane began to climb during the air show flyover.

The intensity of the elevon oscillations increased and resulted in structural stress that ultimately caused the wing to fail and separate

Lockheed Martin F-117A Accident, Sept. 14, 1997
Left-wing Support Structure



Source: U.S. Air Force

Figure 1

about 2.5 feet (0.76 meter) inboard of the outboard elevon, at the no. 11 wing-rib position.

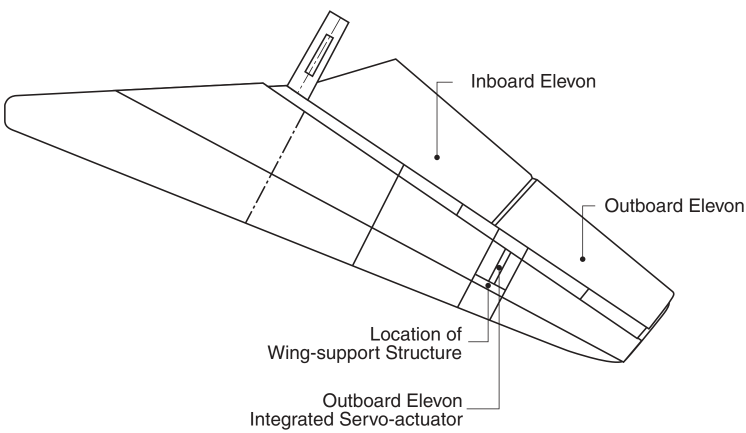
The accident airplane was built in 1983 and had accumulated 2,585 flight hours. The Air Force said that the pilot's preflight inspection on the day of the accident had revealed no discrepancies. A review of maintenance conducted during the previous 30 days (14 items) revealed nothing that could have been involved in the accident.

A further review of the airplane's maintenance history by the Air Force showed that substantial modifications had been performed between 1992 and 1996 on the support structures in both wings and the outboard-elevon ISA in the left wing.

The wing-support structures in the F-117 fleet had a history of maintenance problems that began in 1988. The problems were caused by loose Taper-Lok and Hi-Lok fasteners; elongated bolt holes; and cracked support "T" (T-shaped) brackets.

Two T brackets, four "L" (L-shaped) brackets and several fasteners affix each wing-support structure to the no. 14 wing rib and the no. 15 wing rib in the ISA bay. Fasteners also affix

Lockheed Martin F-117A Accident, Sept. 14, 1997 Left Wing



Source: U.S. Air Force

Figure 2

steel caps to the top and bottom of each support structure.

During a scheduled (no. 3 phase) inspection in January 1996, the support structures in both wings of the accident airplane were found to flex up and down. The aircraft manufacturer recommended removal and repair of the structures. The manufacturer provided on-site technical assistance and tools, and Air Force structural-repair personnel removed, repaired and reinstalled the structures at an Air Force field maintenance facility.

The repairs consisted of stripping paint; resizing holes; conducting nondestructive inspections; installing new, oversized fasteners; and repainting. The repairs required two weeks to complete.

The Air Force said that when the structural-repair personnel reinstalled the wing-support structure in the left wing, they apparently failed to install four Hi-Lok fasteners on the upper inboard L bracket that attaches the structure to the no. 14 rib.

The Air Force said that two people in key maintenance-management positions at the field maintenance facility were in transition (that is, they had received new job assignments) and that no one had been assigned to another key maintenance-management position at the facility. The Air Force did not say what effect, if any, this staffing situation had on the events leading to the accident.

The Air Force found no record in the computer database (the core automated maintenance system [CAMS]) of the removal, repair, reinstallation and inspection of the wing-support structures by Air Force technicians. A record had been made on paper, but had been discarded; such paperwork is not required to be retained beyond three months.

Maintenance personnel from at least four different Air Force technical groups, an Air Force engineering technical service representative and the aircraft manufacturer's representative had been involved in the removal, repair, reinstallation and inspection of the wing-support structures.

Structural repair personnel had installed the wing-support structure in the left wing. The aircraft's crew chief or wing phase-inspection personnel then had installed the outboard-elevon ISA and the steel cap. With the cap installed, the wing-support structure and its rib attachments no longer were visible.

Air Force aircraft are maintained, in part, according to procedures in specific technical orders (TOs). There was no TO for removal, repair and reinstallation of the wing-support structure. Therefore, submittal of a maintenance-assistance request

(MAR) by the field maintenance facility and approval of the request by appropriate Air Force authorities were required before the work was begun.

The Air Force said that it found no MAR or written record of approval for the work, although some documents indicated that verbal approval for the work had been given.

Air Force officials with authority to approve the work said that they were aware that the steel caps were being removed, but were not aware that the entire wing-support structures would be removed, repaired and reinstalled. Some officials referred to the steel caps as part of the wing-support structures; other officials referred to the caps as components that are not part of the wing-support structures.

Some maintenance personnel interviewed by investigators said that the repair of the wing-support structure was complex and normally would be conducted at a depot maintenance facility, rather than at a field maintenance facility. They said that the deficiencies in documentation of the work resulted, in part, from conducting the work at the field facility.

A no. 4 phase inspection of the airplane was conducted in July 1996. The left outboard-elevon ISA and the ISA attachment fittings were inspected. CAMS records showed that two technicians conducted the inspection, but Air Force investigators discovered that the inspection actually was conducted by three other technicians.

The inspection required removing the top steel caps, but not the wing-support structures. The three technicians who removed the steel cap from the left-wing-support structure said that they could not recall if the four Hi-Lok fasteners were in place.

Records show that no further maintenance or inspections of the ISA bay were conducted before the accident occurred.

The accident aircraft was at a depot maintenance facility between August 1996 and November 1996. A time compliance directive (TCD) recommending inspection of wing-support-structure fittings was not conducted during a depot visit.

The TCD had been issued in January 1996 (the same month that the wing-support structure in the accident aircraft was repaired at the field maintenance facility). The directive recommended inspection of the Taper-Lok holes, Hi-Lok holes and T brackets in all F-117A wing-support structures. The TCD said that the inspection should be conducted at a depot maintenance facility within one year of issuance of the directive or whenever parts became available.

The Air Force said that because of contractual and budgetary constraints, the inspection recommended by the TCD was not conducted when the airplane was at the depot facility.

In June 1997, a major (no. 1 phase) inspection was completed. Following the inspection, an Air Force pilot with three years of flight experience in F-117s flew a Northrop T-38 behind the accident airplane. The pilot observed that the outboard elevon on the accident airplane's left wing was deflected approximately two inches (5.1 centimeters) upward while the airplane was in level flight.

The T-38 pilot reported the abnormal deflection. No written procedure existed for investigating the abnormality. Nevertheless, an exterior visual inspection was conducted on the ground. The Air Force said that the maintenance technicians found only 0.5 inch to 0.75 inch (1.3 centimeters to 1.9 centimeters) deflection and concluded that this was acceptable. No further action was taken.

In October 1997 (one month after the accident occurred), the TCD recommending inspection of F-117 wing-support structures was revised to require compliance "not later than next depot input." The Air Force said that the revision was made because of an administrative error in issuing the original TCD, not because of the accident.

Maintenance Errors Analyzed

An analysis of the Air Force report suggests events and factors that could have influenced the course of events that led to the omission of the wing-support-structure fasteners (readers may formulate other possible events and factors contributing to the maintenance error). The codes appearing in parentheses, in order of priority assigned by the author, are explained in Table 1.

- The technicians who reinstalled the repaired support structure in the left wing in early 1996 failed to install four Hi-Lok fasteners (W, S, C, P, O);

- A postinstallation inspection of the wing-support structure may not have been conducted or may not have been conducted properly (S, I, P, C);

- The crew chief or the phase inspection personnel who installed the top steel cap on the wing-support structure did not discover that four Hi-Lok fasteners were omitted (W, P);

- The omitted fasteners were not discovered during the July 1996 inspection of the outboard-elevon ISA and ISA attachment fittings (I, T, W);

Table 1
Factors Involved in Maintenance Error

Code	Factor	Related Elements
C	Communications	Verbal, written, visual
D	Design	Original, modification
E	Environment	Weather, lighting, indoor temperature, noise
I	Inspection	Preliminary, progressive, final; NDI, duplicate
H	Hardware	Equipment, tools, parts, material, etc.
L	Limitations (physical), ergonomics	Weight, reach, sight
M	Manufacturer manuals	Instructions, service bulletins, aircraft flight manuals, alerts, data, etc.
O	Organizational structure and top management	Division of and/or shared responsibility, support recources, safety commitment and assurance
P	Paperwork and its systems	Logbooks, records, documentation, etc.
R	Regulations	Design, operating, airworthiness, etc.
S	Supervision and middle management	Work assignment and oversight, decision making
T	Training	Basic skills, aircraft technical, administration, human factors
W	Worker	Aircraft maintenance, licensed, nonlicensed, ground-support staff
X	Physiological, psychological	Stress, fatigue, drugs, alcohol, etc.

Source: Bart J. Crotty

- Records misidentifying personnel who had conducted maintenance on the accident airplane, the absence of records of several repairs and inspections of the airplane, and noncompliance with procedures for seeking MAR authority show that strict control of maintenance was lacking (P, S, C, O);

- With two key maintenance-management positions at the field maintenance facility staffed by personnel in transition, and with another key maintenance-management position vacant, the opportunity existed for potentially inadequate supervision of the removal, repair and reinstallation of the wing-support structure (O, S, C);

- The decision to conduct the removal, repair and reinstallation of the wing-support structure at the field facility was questionable, because the facility lacked full management capability and because the removal, repair and reinstallation of the wing-support structure were complex tasks (O, S, L);

- Discovery that fasteners were omitted from the wing-support structure likely would have been made when the accident airplane was at the depot maintenance facility, if the TCD had required, rather than recommended, inspection of the support structure when the airplane was at the depot facility (P, I, S, O, C) ; and,

- Following the T-38 pilot's report, the conclusion of maintenance technicians that the elevon deflection was acceptable was not based on specific, established criteria and precluded a more thorough investigation that might have revealed degraded structural integrity (S, L, C).♦

Editorial note: This article was based on U.S. Air Force Accident Investigation Report *F-117A, SN 81-000793, 7th Fighter Squadron, 49th Fighter Wing, Holloman Air Force Base, New Mexico, 14 September 1997, Near Martin State Airport, Maryland*. The 795-page report contains diagrams, color photographs and appendixes. The maintenance-error analysis presented by the author is not part of the report.

About the Author

Bart J. Crotty is an airworthiness and maintenance consultant. He is a former U.S. Federal Aviation Administration airworthiness inspector and trainer, and designated airworthiness representative. Crotty has worked for repair stations, airlines, an aircraft manufacturer, law firms, safety organizations and several non-U.S. national civil aviation authorities. His career spans 38 years, approximately half of it in non-U.S. locations. He has an airframe and powerplant certificate and a bachelor of science degree in aeronautical engineering.

Wing Component Adjustment with B-747 On Jacks Produces Panel Loss in Flight

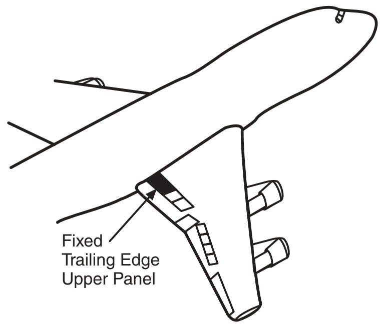
Bart J. Crotty

During climbout shortly after takeoff, the flight crew and cabin crew felt an unusual vibration thought to be coming from the right side between doors no. 3 and no. 4 of their Boeing 747. The vibration could also be felt through the cabin floor. When the aircraft reached cruise-flight level, the vibration eventually stopped.

Several hours later, at the destination airport, an inspection found that a large area of the right-wing fixed trailing-edge upper panel (Figure 1), also known as the "flying panel," was missing. Inboard areas of the upper surfaces of the fore- and mid-trailing-edge wing flaps were badly damaged.

Investigation revealed that the flying panel showed signs of hammering against the fore-flap upper surface, producing two deep grooves. Underneath the flying panel, the inboard diagonal tie-rod at the no. 1 rib was bent and bowed laterally outboard in compression and had fractured across the lower drain/vent holes. Metallurgical examination showed that the tie rod had failed because of low-cycle and high-stress bending fatigue, indicating that a cyclic force had been involved in the failure.

Location of Boeing 747 Right-wing Fixed Trailing-edge Upper Panel

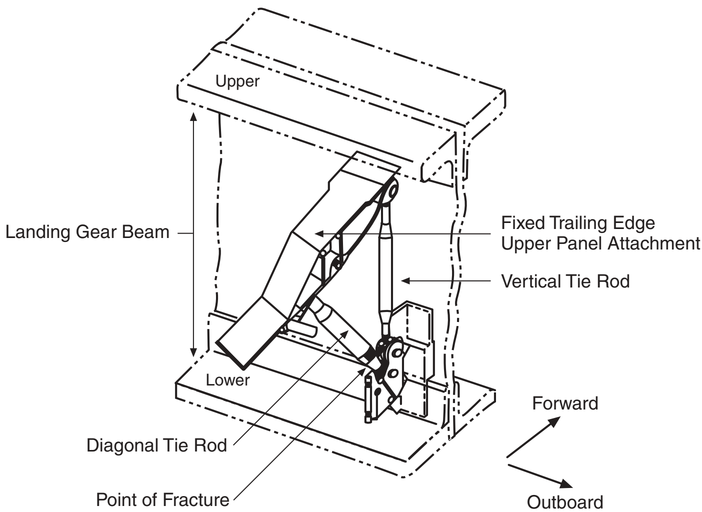


Source: Boeing Commercial Airplane Group

Figure 1

An investigation determined that about 160 cycles to 240 cycles had occurred from the start of the crack until failure. It was further determined that the tie rod had been adjusted to extend its length, and that the adjustment appeared to have been accomplished using a "Stilson/pipe wrench"

Boeing 747 Fixed Trailing-edge Upper Panel Substructure



Source: Boeing Commercial Airplane Group

Figure 2

tool on the larger diameter of the tie rod, resulting from the lengthening adjustment (Figure 2).

A review of maintenance records showed a major repair of the flying panel, but no evidence could be found that this repair was less than satisfactory, nor were any other material or structural defects found that could explain the failure of the tie rod and damage to the flying panel and other surfaces. About five months earlier, the aircraft had undergone a heavy maintenance check for three months and had been performed by an overseas contractor. A records review did not reveal any maintenance performed since then that would have involved adjusting the subject tie-rod length. The aircraft had operated for 230 flights since leaving the contractor's facility before failure of the tie rod.

During installation and rigging of a replacement flying panel by the operator, an accident-investigation-authority inspector observed that, in the aircraft maintenance manual, in a chapter covering removal, installation, adjustment and rigging procedures were difficult to follow and ambiguous in some areas. The operator considered this observation but decided that changes to the manual were not required. The manual does caution that adjustments of the flying panel should be made with the aircraft "on the gear" (meaning not on jacks).

The investigation concluded that the inboard diagonal tie-rod failure occurred from compression forces acting repeatedly to bend the rod until fracture occurred after about 160 cycles to 240 cycles. This allowed the flying panel to lose its rigged form and strike the upper surface of the fore flap. These abnormally high forces resulted from incorrect adjustment to the tie rod, possibly while the aircraft was on jacks. If so, when the aircraft was later placed on the ground, the landing-gear beam may have induced higher loads than the tie rod was designed to absorb. The tie-rod fatigue-fracture striation suggested that the incorrect adjustment had occurred during the last major maintenance.

Several aspects of this apparent maintenance-error accident suggested lessons to be learned or relearned, based on the author's opinion (see Table 1, page 12). It should not be inferred that all the following areas were the cause of, or contributed to, the incident.

Maintenance Errors Analyzed

1. Maintenance, i.e., adjusting the tie-rod length, was performed but not recorded. (W,S,P)

2. The manufacturer's maintenance manual requirement for tie-rod adjustments to be performed only with the aircraft on the ground was not followed. (W,S,T)

3. A strap wrench, not a pipe wrench, should have been used during the adjustment. It is very disturbing that a maintenance worker would use a pipe wrench when it should have been obvious that a pipe wrench damages the surfaces that it engages. (W,S,H,T)

4. Though not mentioned in the incident report, it is assumed the pipe wrench–damaged surface area of the tie-rod shaft was not the site of the failure.

5. The apparent widespread breakdowns of correct procedure in items nos. 1, 2 and 3 leaves doubt that the contractor organization's management and supervision of workers fulfilled basic responsibilities. (O,S)

6. The possibility that the manufacturer's maintenance-manual

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R	Regulations	Design, operating, airworthiness, etc.
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T	Training	Basic skills, aircraft technical, administration, human factors
W	Worker	Aircraft maintenance, licensed, nonlicensed, ground-support staff
X	Physiological, psychological	Stress, fatigue, drugs, alcohol, etc.

Source: Bart J. Crotty

warning was not explicit or strong enough, or that other operator errors have been made, suggests that a separate alert should have been issued. (C, M)♦

Editorial note: This report is based on U.K. Aircraft Accidents Investigation Branch (AAIB) Incident Bulletin No. 3/97, ref. EW/C96/10/1. The maintenance-error analysis presented by the author is not part of the bulletin.

MRO 99 Scheduled for Atlanta

The Maintenance, Repair & Overhaul Conference & Exhibition (MRO 99) will take place April 6–8, 1999, at the Cobb Galleria Centre, Atlanta, Georgia, U.S. For registration information: Alejandro Wyss, +(212) 512-3047.

Asian Aerospace Plans Aerospace and Defense Technology Exhibition and Air Show

Asian Aerospace 2000, the 10th aerospace and defense technology exhibition and air show, will take place February 22–27, 2000, at Changi Exhibition and Convention Centre, Singapore.

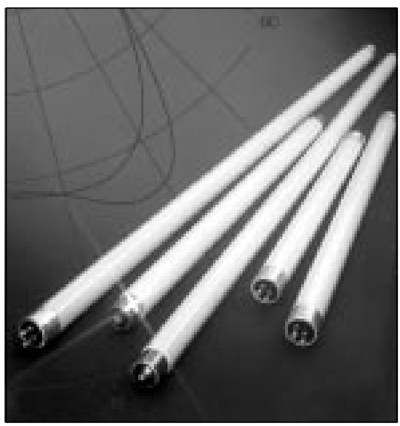
According to the show's organizers, attendance in 1998 was nearly 25,000 including more than 5,000 maintenance and engineering specialists.

For more information: Reed Exhibition Companies, 383 Main Avenue, Norwalk, CT 06851 U.S. Telephone +(203) 840-5342. Reed Exhibition Companies, Oriel House, 26 The Quadrant, Richmond, Surrey, TW9 1DL England. Telephone +(44) 181 9107746.

New Line of Fluorescent Lamps Introduced

Chicago Miniature Lamp has a new line of T-5 fluorescent interior wash lamps designed as industry-standard replacements for general aviation and commercial aircraft. The lamps are available in warm-white and cool-white colors, standard four-watt, six-watt, eight-watt and 13-watt ratings with miniature bi-pin or pinless bases, and in lengths of six inches (15 centimeters), nine inches (23 centimeters) 12 inches (30 centimeters) and 21 inches (53 centimeters).

The company also makes fluorescent, compact fluorescent, high-intensity discharge, incandescent,



Chicago Miniature Lamp's T-5 Fluorescent Lamps halogen and neon lamps, light-emitting diodes, and specialty lamps as well as fiber optic light systems, standard design fixtures and value-added lighting assemblies.

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Air Hydraulic Pumps Feature Flexibility, Ease of Use

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The pumps operate on 40 pounds to 120 pounds per square inch (three bar to eight bar) shop air and have a maximum pressure output of 10,000 pounds per square inch (700 bar). Additional features include an extra-large fill port, an integral safety-relief valve in case of overfilling of the reservoir and a sealed reservoir to prevent leaks and contamination of oil by ambient air, says the manufacturer.

For more information: SPX Power Team, 2121 W. Bridge St., Owatonna, MN 55060-0993 U.S. Telephone (800) 541-1418 (United States and Canada) or +(507) 455-7100.

Airborne Ultrasonic Detector Adds Flexibility, Increases Inspection Possibilities

The Curlin-Air portable ultrasonic flaw detector uses an airborne ultrasonic beam to identify flaws in a wide variety of materials, according to the manufacturer, NDT Systems.

NDT says that materials formerly considered uninspectable can be examined using the unit's hand-held yoke. Structural flaws such as delaminations, splits, blows, inclusions, cavities, impact damage, and fractured or crushed cores cast a "shadow" in the signal-amplitude display and actuate an alarm.

The Curlin-Air Portable Ultrasonic Flaw Detector

The unit is suitable for use with many common industrial and aircraft materials such as foams, laminates, rotor blades, ceramics and circuit board stock. It also can be used as a densiometer with plastic foam materials and for detecting water trapped in honeycomb aircraft structures, says the manufacturer.

For further information: NDT Systems, 15752 Graham St., Huntington Beach, CA 92649 U.S. Telephone (800) 455-4638 (United States and Canada) or +(714) 893-2438; Fax +(714) 894-2602.

1998 FARs on CD–ROM

SOLUTIONS Software Corp. offers U.S. Code of Federal Regulations (CFR) updated to the U.S. Government Printing Office's (GPO) 1998 revision level including Title 14, Aeronautics and Space (FARs). The two-CD set containing all 25 CFR titles sells for US$62.50.

The CDs are created from official GPO electronic source files, and include complete PDF graphics as well as Adobe Acrobat 3.01 Reader + Search software for Windows, Macintosh and Unix, says the manufacturer.

For further information: SOLUTIONS Software Corp., 1795 Turtle Hill Rd., Enterprise, FL 32725 U.S. Telephone +(407) 321-7912.

Seton Evacuation Plan Sign

Signs Provide Evacuation-plan Information

Seton Identification Products' Evacuation Plan can provide evacuation and safety information at a glance on a color-coded, nonglare sign. The plan includes a sign holder to display a facility's floor plan and evacuation routes, with inserts that can be updated as changes occur. Zones are color coded, and locations of extinguishers, pull alarms and other fire equipment are identified, says the manufacturer.

For more information: Seton Identification Products, Dept. YDO, P.O. Box 819, Branford, CT 06405 U.S. Telephone: (800) 243-6624 (United States and Canada), or +(203) 488-8059 x 4173.

High-pressure Hydraulic Hoses Feature Enhanced Strength, Efficiency

Enerpack's new 700-series of thermoplastic, high-pressure hydraulic hoses accommodate a maximum working pressure of 10,000 pounds per square inch (690 bar) and experience 77 percent less expansion per foot (0.3 meter) for higher efficiency, says the manufacturer.

The hoses feature four-layer construction including two layers of steel-wire braid, are 25 percent lighter than conventional rubber hoses and have a high-visibility bright yellow color, according to Enerpac. The hoses are available in 0.25-inch and 0.38-inch (0.64-centimeter and 0.97-centimeter) internal diameters, two-foot to 50-foot (0.61-meter to 15.25-meter) lengths, and one-ended or two-ended assemblies.

Enerpac Thermoplastic High-pressure Hoses

For more information: Enerpac, 13000 West Silver Spring Dr., Butler, WI 53007-1093 U.S. Telephone: (800) 433-2766 (United States), (800) 426-4129 (Canada); or +(414) 718-6600.

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GRIPPERS for STRIPPERS™ are low-cut, over-the-shoe covers designed to provide wet-surface traction and prevent slip-and-fall accidents without damaging the surface, says Jordan David, the manufacturer. They are ideal for work in any situation with polished floors, wood, polyurethane or metal underfoot surfaces and/or frequent spills of liquids including organic or petroleum products. The soles feature a vinyl-loop material that provides traction and slip resistance in liquids such as grease and oil.

The pull-on covers feature a clean arch for ladder climbing and a kick-off lug for fast removal, and are available for U.S. men's footwear sizes 8 to 14.

For more information: Jordan David, 400 Babylon Rd., Horsham, PA 19004 U.S. Telephone: (888) 667-5477 (United States and Canada).♦

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11th annual
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March 8–10, 1999

Grand Hotel Krasnapolsky, Amsterdam, Netherlands

Among the topics are propulsion system malfunction;
rushed and unstabilized approaches; and alertness technology:
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