The Mechanic and Metal Fatigue

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by
Robert A. Feeler
Maintenance Consultant

A significant part of a technician's work involves looking for defects in aircraft structural components, even if the technician's primary job responsibility is not that of an inspector. Routine checks and inspections performed call for him to examine various components and areas of the airframe and powerplant to assure that they are free from defects which might adversely affect airworthiness and safety of flight.

Metallic components rarely fail from overload, provided the aircraft is operated within its design limitations. The designers have assured that adequate margins of strength are incorporated into the aircraft to safely withstand normal loads with a significant margin of safety. Abnormal conditions such as inflight turbulence, overweight landings, hard landings, etc. do occasionally occur, however, and the special inspections called out in every manufacturer's maintenance and operating manuals are specifically designed to detect any evidence of abnormal deterioration or failure exerted by such abnormal operation.

Much more common and of constant concern to the average technician, however, is failure due to fatigue in metallic components. In order to more readily detect indications of fatigue failures and assure that the aircraft is airworthy and safe for operation, it is important that the technician have a good understanding of the metal fatigue phenomena, its causes and what can be done to prevent it. The formal study of the causes and mechanisms of fatigue is called "fracture mechanics," but this discussion will touch on only the very basic aspects of this branch of engineering knowledge.

Metal's properties that are useful in discussing its susceptibility to fatigue are the tensile strength and elasticity of the base metal.

- *Tensile Strength*. A metal's resistance to being pulled apart, usually expressed in pounds per square inch.

- *Elasticity*. That property which allows a piece of metal to resume its original form after a distorting force is removed. The limiting value of stress at which elasticity finally ceases is known as the *elastic limit*.

The specific values of these properties for various materials have been determined by laboratory and field testing. The aircraft designer's task is to ensure that there is enough metal in the cross section of a metal part to provide adequate tensile strength for the maximum load, and that the elastic limit will not be exceeded under anticipated stress levels in normal operation.

Avoiding Fatigue in Basic Design

The designer's task would be easy if every piece of an aircraft were under a constant load; it was in the form of a perfect bar shape with no defects in the material; it had no curves, bends, or changes in cross section; and it had no holes or surface imperfections. However, since every piece of an airframe structure is exposed to all of these variables and the stresses in each piece are irregular and cyclic, the resultant stress concentrations under constantly changing conditions can induce the phenomenon called fatigue.

The eventual result of fatigue can be a total failure of the part, and this may occur at a load level well below the tensile strength of the material. However, before this occurs, a crack will be growing with each cycle of stress that exceeds the elastic limit at a specific point in the part. This concentration of stress can start from:

- a metallic defect in the material

- a scratch or tool mark

- a design fault that creates an inadvertent point of stress in excess of the intended limits.

Regardless of what initiates the crack, it will grow through the base metal, splitting the material apart grain by grain, until such time as the remaining material can no longer sustain the applied load. At this time, the next cycle of stress causes total metal fracture and the part fails.

In the manufacturing process, the engineer has several items at his disposal to improve the fatigue resistance of a part. Elimination of tool marks and scratches are obvious methods of eliminating stress risers. Precision fitting during assembly and close-tolerance fasteners avoid uneven loading and reduce the exposure to localized stresses and resultant fatigue.

Perhaps the least understood process however, is that of pre-stressing the part so that the base material never "feels" the cyclic loads applied in operation. Pre-stressing techniques vary from torquing of bolts and nuts to various surface treatments that compress the surface of the part.

How to Pre-stress Aircraft Fasteners

When he applies a specified torque to a critical bolt, the technician is not doing so just to keep it tight. The real reason for bolt torqueing is to pre-load, or stretch the bolt so that the applied load exceeds the stress levels which can be expected in normal service. The part, therefore, exists in a level stress condition which, if the designer has done his job correctly, never exceeds the elastic limit of the part. Regardless of the fluctuations applied in service, the properly pre-stressed bolt is not affected by the cyclic or changing stresses applied during the normal operation of the aircraft.

It is not possible to measure actual stress with the tools normally available to the typical technician; therefore, the desired pre-stress levels have been calculated and converted to bolt torque readings to provide a convenient and accurate method of measuring the load applied to the part. Anything such as lubricants, burrs or irregularities on the contact surfaces can affect the torque needed to apply the pre-stress intended. Although these cautions tend to become monotonous, their importance should not be overlooked.

A little unintended grease on bolt threads can reduce the turning friction to the extent that the correct torque will overstress the part and could result in a tensile failure. Conversely, a burr or irregularity on the contact surfaces could cause an apparently proper torque indication which is incorrect when the burr or irregularity wears down or settles in. This then results in loss of the intended pre-load of the part and subjects it to the destructive cyclic forces of fatigue.

Extremely critical parts such as turbine tie bolts are sometimes prestressed on the basis of the actual stretch of the part rather than the torque on the threaded nut. This is a much more accurate method of measuring the pre-load applied because it discounts any friction error.

Another variant of the pre-stress measurement techniques of fasteners uses a "pre-load-indicating" (PLI) washer. This consists of a sandwich washer having a free ring sandwiched between two bearing surfaces. When the pre-load is applied, the pressure surfaces compress and pinch the free ring. The proper stress has been applied when the free ring is locked between the surfaces and cannot be rotated.

How to Pre-stress Other Parts

Most structural components are subjected to bending stresses in one form or another. In subjecting a part to bending loads, the outer surface undergoes the maximum stretching force. When this force exceeds the elastic limit at a localized stress point, the grain boundaries will separate, and a crack is initiated.

The surface area can be pre-stressed by compressing the outer layer to induce compressive stresses in excess of the tensile stresses anticipated in service. This compressed surface then forms a sort of insulating layer which protects the base material and reduces the exposure to fatigue cracking.

Among the processes used to pre-stress the surfaces of parts are:

- *Rolling*. Used primarily on flat stock.

- *Shot or ball peening*. Especially effective to improve the fatigue resistance of a part that may have surface imperfections or machining marks. The process closes surface imperfections and compresses the surface of the material. It can be uniformly applied regardless of the shape or size of the part.

- *Forging*. Striking under a forming die as with a forged fitting.

Holes Get Special Fatigue Treatment

Any hole in a structural part makes the metal more susceptible to fatigue because the hole alters the stress patterns within the material and concentrates the stress around the periphery of the hole. Any nick, burr or tool mark in or around the hole creates a further stress concentration and accentuates the exposure to initiation of a fatigue crack.

Special reaming of critical holes and fitting of close tolerance fasteners can minimize the exposure to fatigue, but these treatments can only make the best of the available strength and do nothing to improve it. There are, however, special processes which actually improve the fatigue resistance at holes in structural components by creating a compressive layer around the hole. This layer then shields the hole from the applied stresses and greatly reduces its susceptibility to fatigue cracking. The oldest of these processes is that of using an *interference fit* — the use of a tapered pin or an interference (oversize/shrink fit) fastener to attach structural components to create a compressive stress at the hole by exerting force against the sides of the hole. While this method is effective, it also introduces other potential problems such as scoring or abrasive damage which can be induced during installation.

Engineers have learned that a minute radial expansion of the hole itself creats a residual compressive stress around the hole. The compressed zone effectively shields the hole from cyclic tensile stresses in much the same way that torquing a bolt reduces its exposure to cyclic fatigue. Several methods have been devised to expand a hole (Figure A):

- *Stress coin hole expansion*. This can be applied to smaller holes by pushing a mandrel with three rounded rings of slightly increasing diameters through the undersized hole to form the compressive layer.

- *Roll peening*. This was originally developed to improve the surface finish in larger holes. The process uses a small roller under extreme pressure to compress the inner layer as it is rolled within the bore.

Photograph not available.

Figure A

- *Split-sleeve hole expansion*. First explored by a major airframe manufacturer in the late 1960s, this process has been perfected and expanded and is now a patented process owned by Fatigue Technology Inc.(FTI) and registered under the trademark of "Cx," an acronym for *cold expansion***.** The basic process involves inserting a bushing into the hole and pressing it against the wall of the hole by pulling a mandrel of increasing diameter through it. The result is a cold expansion of the hole and concurrent installation of a bushing that protects the the hole's wall. Tests have shown that metal specimens with holes reworked with the Cx process had fatigue performance nearly equal to specimens with no holes at all.

The cold-expansion process has also been proven to be a very effective means of retarding further growth of minute fatigue cracks which are detected in fastener holes and perhaps even more interesting, as a repair technique to treat the hole that is drilled in sheet metal to terminate an existing crack.

Typically, stop-drilling a hole at the tip of the crack is intended to reduce the stress concentration and to, hopefully, retard further crack growth. Unfortunately, cracks often reinitiate from the stop-drilled hole or are a result of not accurately locating the tip of the crack during the stop-hole drilling procedure.

FTI has conducted tests which indicate that there is significant improvement in fatigue life when a stop-drilled hole is expanded using the company's patented split-sleeve, cold expansion process. Testing showed that cold expansion of the stop-drilled hole was even able to substantially retard the growth of a .100-inch residual crack that extended beyond the stop hole. This s*top crack (SCcx)* process is apparently able to arrest further growth of a crack test sample for more than 1,000,000 cycles as compared to lives of 1,400 to 2,400 cycles for a non-cold expanded stop-drilled hole with the same residual crack length.

Although the *SCcx* process is not intended as a permanent repair, FTI data indicate a substantial improvement in the fatigue life of a cracked piece until such time as a permanent repair or replacement can be accomplished. Special tooling for field application of this process is available from the manufacturer. Technicians are reminded to check the airframe manufacturer's structural repair and maintenance manuals to assure that any defects are within acceptable limits before using this process.

A similar cold-expansion technology is also being used to provide the interference fit required for bushing installation in airframe structural components. Bushing interference is defined as the degree to which the bushing's outside diameter is greater than the inside diameter of the hole. Traditional techniques using dry ice or liquid nitrogen to shrink the bushing are limited to diametrical interferences of .002 to .003 inches. FTI has perfected tooling and processes under the trade name of *ForceMate (FM)* which have shown the ability to achieve interference of .004 to .008 inches in a nominal 1-inch diameter bushing.

The FM process which is depicted in Figure B has the additional advantage of reducing the exposure to wearing corrosion and at the same time, reduces the exposure to fatigue cracking around the hole because the hole itself is cold-expanded to induce the protective stress layer described earlier. Following the bushing installation/expansion, the inside diameter must be finish reamed to size. As in the other cold expansion processes, the specialized tooling is available only from the manufacturer.

Illustrations courtesy of FTI

Technician Plays a Role in Maintaining Fatigue Resistance

All of the technology outlined above is to no avail when the fatigue resistance afforded by these treatments is reduced by lack of maintenance or faulty maintenance practices.

In performing routine tasks involving the removal and reinstallation of structural components and fasteners, the technician must be alert to anything which will affect proper torque of critical fasteners. Among many safety practices in this area are:

Photograph not available.

Figure B

- Holes should be inspected for burrs, nicks and corrosion before reinstalling fasteners.
- Mating surfaces should be clean, flat and free of defects.
- New components should be checked for proper and full contact on mating surfaces.
- Fastener and nut threads should be checked for condition and full contact. Locking devices or self-locking inserts should be replaced, not reused.
- Fastener-to-hole fits and clearances should be checked with a micrometer where close tolerances are called out.
- Torque wrenches should be properly calibrated and conscientiously used. "Elbow torque" is not a suitable substitute for a torque wrench.

Maintenance practices when working with other components or structural members which have been subjected to special surface treatments or installation processes should be reviewed to assure that original manufacturing processes are not inadvertently deleted. For example:

- If a surface defect is removed by grinding, it may be necessary to re-shot peen the area to restore the surface protection.
- If a hole is bored oversize to accommodate a fastener or to maintain alignment, it may be necessary to rework the hole with the cold-expansion process to restore the fatigue resistance of the original part.
- If additional fasteners are installed in the course of a structural repair, it may be necessary to treat the new holes with the cold-expansion process to maintain the fatigue resistance of the component.
- If a bushing is replaced, the installation method or interference fit must be in accordance with the original manufacturer's approved process.
- Even minute rework on a forged part may adversely affect the structural strength or fatigue resistance of the piece.

Check the structural repair manual or contact the manufacturer when in doubt.

By continual awareness and care, the aviation maintenance technician is an important link in the chain of events that helps an aircraft to fly from A to B without expectation of structural failure that occurs as a result of fatigue. ♦

NEWS & TIPS

FAA Issues Directives On Aircraft Corrosion Prevention

The U.S. Federal Aviation Administration (FAA) has issued directives for monitoring and correcting corrosion on nearly 3,000 Boeing transport aircraft stemming from the April 1988 incident in which corrosion was found in an Aloha Airlines Boeing 737 that lost a large part of its fuselage during flight. About 1,512 of the Boeing aircraft subject to these directives are registered in the United States.

U.S. airlines operating Boeing 707, 727, 737 and 747 aircraft now are required to develop corrosion prevention and control programs by December 12, 1991. The mandated programs are intended to prevent structural degradation due to corrosion and a combination of corrosion and fatigue, according to the U.S. Department of Transportation (DOT). The FAA also has issued a notice of proposed rulemaking (NPRM) for similar corrosion control programs directed at McDonnell Douglas DC-8, -9 and -10 aircraft. Following the Aloha incident, the FAA sponsored an international conference on aging aircraft, which was followed by the formation of a joint government/industry task force to develop a modification program to ensure the safety of older aircraft.

Scholarship Program Offered to Youth

The Experimental Aviation Foundation (EAF), the educational branch of the Experimental Aircraft Association (EAA), recently announced the continuation of its extensive scholarship program intended to encourage aviation studies and careers among the nation's youth. The foundation's scholarship program has helped more than one hundred students begin or continue their aviation studies.

Chuck Larsen, EAF education director, said these scholarships have generated grants to help aspiring pilots, mechanics and a growing number or other aviation professionals. "The goal of the foundation's scholarship program is to encourage, recognize and support excellence in pursuit of knowledge in aviation technologies and skills," Larsen said. He explained that the scholarship program is open to all young people interested in aviation careers. Applicants should be "well-rounded individuals involved in school and community activities as well as aviation, and should have established an academic record that will show an ability to successfully complete the activity for which they are requesting the scholarship."

Applications for the EAF scholarship program and additional information on specific scholarship opportunities can be obtained from the EAA Aviation Foundation, Education Department, EAA Aviation Center, P.O. Box 3065, Oshkosh, WI 54903-3065 U. S. Telephone (414) 426-4888.

Education Group Offers NDT Training Curriculum

The MQS Training Group located in Elk Grove Village, Illinois, U. S., has announced the offering of a complete curriculum of non-destructive training classes that meets the requirements for certification under the Society of Non-destructive Testing (SNT) specification SNT-TC-1A and MIL STD-410.

Ten courses are offered at the school. Course titles include Magnetic Particle, Liquid Penetrant, Basic Ultrasonic Inspection, Ultrasonic Weld Inspection, Fundamentals of Radiography, Applications of Radiography, Eddy Current Testing, and General NDT.

The courses are described in a brochure which also highlights the school's accreditation, instructional techniques, course materials and registration information. Additional information can be obtained from MQS Training Group, 2301 Arthur Avenue, Elk Grove Village, IL 60007 U.S.

Call for NDT Papers

The American Society for Nondestructive Testing (ASNT) has issued a call for papers for its 1991 Fall Conference, titled "Improved Safety and Reliability Through NDT." The conference is scheduled to be held at the Sheraton Boston and Hynes Convention Center, Boston, Masssachusetts, U. S., September 15-18, 1991.

The conference, which celebrates the 50th anniversary of ASNT, will examine the progress that has been achieved in forms of nondestructive testing during the past 50 years. Authors are requested to submit papers that consider the past, present and future of NDT methods and applications, with special emphasis on improvements in safety and reliability.

Interested authors should submit a paper title and abstract, including co-author names and addresses to David Bell, professional program chairman, c/o ASNT's Conference Department, 1711 Arlington Lane, P.O. Box 28518, Columbus, OH 43228-0518 U.S.

MAINTENANCE ALERTS

This information is intended to provide an awareness of problem areas through which such occurrences may be prevented in the future. Maintenance alerts are based upon preliminary information from government agencies, aviation organizations, press information and other sources. The information may not be accurate.

Safety Pins Installed — Almost

The November/December 1990 issue of the *Aviation Mechanics Bulletin* included a report about an inadvertent retraction of the nose gear on a DC-10 aircraft. That incident was caused by a worn lock mechanism on the safety pin. The following report is all too similar — this time it happened on an Airbus A-300.

An A-300 operator recently experienced a nose landing gear collapse during a maintenance check. The aircraft was on wheels, undergoing maintenance outside of the hangar. Safety pins had been installed.

While pressurizing the green hydraulic system to check for leaks in the main landing gear area, the engineer selected the landing gear control lever to the UP position. The nose landing gear then collapsed and the aircraft's nose hit the ramp surface. Damage was caused to the nose landing gear doors, door actuators and to the fuselage area that came in contact with maintenance stairs.

After investigation, the cause of the inadventent gear retraction was confirmed to be the incorrect installation of the nose landing gear safety pin in its housing; the pin was only half engaged into the hole provided. The aircraft manufacturer cautions that every operator follow carefully the aircraft maintenance manual recommendations each time the installation of safety pins is required.

A warning issued by the manufacturer states:

"When the ground safety pin is installed on the nose gear telescopic strut, it is necessary to open the nose gear doors (Ref.32-22-11, P. Block 301) and always visually check that:

- It has completely and easily rotated the fork-type lever of the ground locking system.
- Its top flange abuts against the housing of the telescoping strut locking system (full insertion).
- Before performing the pressurization of the landing gear retraction system, the nose gear

doors must be closed. (Ref. 32-22-11, P. Block 301)"

Don't Believe All Those Advertisements

Some of the current advertisements for various lubricants would have us believe that a squirt of any given product can fix anything. It is not necessarily so. A major U.S. air carrier reports costly damage to the knobs and internal mechanisms of passenger entertainment control units as a result of overuse of such cure-all lubricants.

Apparently, the airline's technicians had been spraying one or more of these all-purpose lubricants on sticking volume controls or channel selectors. Although the initial result appeared to be satisfactory (the control was freed up and the selectors worked properly), the long-term results were far worse. After a period of time, the plastic parts deteriorated.

Controlled tests were conducted in the carrier's shops to evaluate application of the various products available to the line technicians. These tests disclosed that the application of these lubricants on the control knobs resulted in extensive damage and could lead to skyrocketing repair costs beyond that which would be required to properly correct the original malfunction by replacing the component.

Application of one brand of lubricant caused the plastic knobs to soften after 24 hours. Another product caused the electronic parts attached to the knob/shaft to loosen, resulting in total failure of the unit within 48 hours.

Be sure to read the manufacturer's information on the can and be wary of using untried products.

Oil Leak + Dirty Compressor = Fatal Loss of Power

A four-engine turboprop cargo aircraft crashed during an attempted go-around on a training flight in the western United States. Investigation of the wreckage and analysis of the flight and voice recorders disclosed that there were, as in most accidents, several contributing factors, some of which involved flight operations procedures.

Critical to the end result, however, was the fact that at least one and, possibly two, of the four engines was incapable of producing rated takeoff power due to severe contamination of the compressor gas path by an accumulation of oil and tar substances on the compressor blades and stators. Evidence of oil residue was found on the empennage aft of the number one and two engines. The number two engine was not destroyed in the accident and was, therefore, capable of being tested following the accident.

Research into the aircraft's recent maintenance history showed that this engine and propeller had a history of oil leaks. The number two propeller was changed five days before the accident, and records confirmed a higher than normal oil consumption for this model powerplant. Tested later, this engine would only produce 88 percent of rated power.

A compressor wash performed, as recommended by the manufacturer, resulted in only a slight improvement. However, a walnut shell-blast cleaning resulted in substantial improvement and the engine developed 100 percent power.

Maintenance records did not reveal an indication of efforts to clean the gas path following the earlier reports of propeller or engine oil system leakage. The nature of the residues in the engines indicated long-term contamination. The slow but certain deterioration of power output resulted in the inability of these powerplants to respond to rapid demands for increased power when called for during the emergency go-around that ended in an accident.

Bad Vibes End Flight

A two-seat, single-engine aircraft seemed to perform just fine after a major overhaul of its Lycoming O-320 engine. A few days later, however, the owner was startled by a heavy vibration that started after completion of the climbout, just as the airplane reached cruise speed.

Upon reducing power, the vibration reduced and then disappeared completely. A return to cruise power and cruise airspeed brought the vibration back, so the pilot again reduced power and returned to the airport without incident.

The owner/pilot described the symptoms to the mechanic stating that the vibrations started at cruise power upon reaching 110 to 115 mph. He noted that there had been no vibration at full throttle on takeoff, during climb or at pattern airspeed and power.

After some ground checking by the mechanic, the shop decided that the best course of action was to remove the engine and return it to the overhaul agency for a complete teardown. Several weeks later, the engine was returned with a big bill for teardown, but no internal discrepancies had been found.

Another test flight was conducted,

this time with a chase plane in close proximity. When the vibration reoccurred, the pilot in the chase plane immediately spotted the problem. The fairing around the right landing gear strut was loose and upon reaching cruise airspeed, began fluttering so rapidly that it was a blur.

A few rivets and some sealant corrected the cause of the “bad vibes.”

The moral? Communication. The facts were there, but the pilot and mechanic did not communicate sufficiently. Neither did much in the way of diagnosis; both assumed that the most recent maintenance event — the engine overhaul — was the culprit. A little more thorough detective work could have led the thought process to the consideration that the vibration was associated with airspeed, not engine power. ♦

NEW PRODUCTS

No More Working In the Dark

The problem of not being able to see through the typical, nearly opaque arc welder’s face shield has always meant that the operator had to position the welding tip close to the work, drop the visor, and hope he did not move until the arc was struck. A new auto-darkening welding lens claims to solve that problem with a lens that is “transparent” until the arc is struck and then turns dark within 1/500th of a second. The manufacturer claims the Speedglas lens works in either indoor or outdoor light and with any arc welding process.

Photograph not available.

The auto-darkening lens allows the welder to leave the visor in the down position, freeing both hands for work, and further protects the user from being “flashed” by other welders working close by.

The manufacturer states that a built-in non-electronic filter always protects the user’s eyes from damaging ultraviolet and infrared (UV/IR) radiation — even when the lens is in the transparent state. The lens meets

ANSI (American National Standards Institute) standard Z87.1-1989 for eye and face protection and with the hard hat, meets the requirements for industrial head protection.

Further information can be obtained from Speedglas Inc., 2374 Edison Blvd., Twinsburg, OH 44087-2340 U.S.

Air Purifying Respirator Is Lightweight and Self-powered

A battery powered, purifying air respirator is available for technician protection while working in hazardous atmospheres. The maker claims unsurpassed worker comfort due to its low-profile design and comfortable hypoallergenic silicone rubber facemask. This material is able to withstand repeated washings, does not oxidize, and will not dry rot or react with ozone, according to the manufacturer.

The unit is powered by a nicad battery pack worn on the belt of the user that provides eight hours of usage. Recharging of the battery pack requires four to six hours, and protective devices are built-in to prevent overcharging and to maintain the battery at its peak state of charge. The mask assembly weighs 56 ounces and incorporates a single, mask-mounted filter. The unit has been approved in the United States by NIOSH (National Institute for Occupational Safety and Health) to assure compliance with OSHA (Occupational Safety and Health Administration) standards for protective breathing equipment. A speaking diaphragm is built in to the mask to provide for clear communication with other workers.

Photograph not available.

More data on the Powered Air Purifying Respirator (PAPR) is available from Survivair, 3001 South Susan Street, Santa Ana, CA 92704 U.S.

Hot Hands Offer Safety Warning

"Hot Hands" safety lables have been developed by the Wahl Instrument Co. to help prevent burns and injury to unprotected hands or skin. The bright yellow, self-adhesive, circular decals stick to almost any surface, and the graphic depiction of a red hand with the word "HOT" in the center appears when the surface temperature reaches 122 degrees F (50 degrees C). When the surface temperature cools to normal, the warning message and hand disappear.

Each decal is 1.5 inches in diameter, and a bandaged index finger on the red hand is intended to catch the attention of a technician prior to touching the surface. Application possibilities include heated air ducts, ovens, motor cases, etc. The labels can be custom imprinted with customer logos on a special order basis.

Photograph not available.

Further information and a free sample can be obtained from Wahl Instruments, Temp-Plate Division, 5750 Hannum Avenue, Culver City, CA 90231, U.S. Fax (213) 670-2840.

Exam Books Updated

The *Aviation Mechanic General Question Book* and the *Aviation Mechanic Powerplant Question Book* have been updated by publisher IAP Inc. The new editions are effective until September 1992.

The publications are available for the prospective aviation mechanic to study before taking federal license exams. The books contain questions developed by the U.S. Federal Aviation Administration (FAA) for use in written exams for the airframe and powerplant (A&P) certificate; an answer key is provided for each question book. IAP has also developed an FAA exam book for each question book that includes the FAA questions plus the complete answers with explanations and references for each question. Each FAA exam also includes an oral and practical test after passing the written portion, so an oral and practical test guide are included in each exam book.

Information and prices are available from IAP distributors or from IAP Inc., P.O. Box 10000, Casper, WY 82602-10000, U.S. ♦