APPLICATIONS OF OPTICAL DEVICE DURING MAINTENANCE OF AIRCRAFT

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Abstract: During aircraft maintenance 'Optical technique' is contributing a significant role to detect discontinuities on aircraft structure, components and installed engine. With the minimum part preparation this technique has proven the most effective nondestructive method in aerospace industry.
Optical instruments are widely accepted during aircraft maintenance, mainly for two reasons i) to magnify discontinuities that can not be detected by the naked eye and ii) to permit visual checks of critical areas not accessible to unaided eye and difficult for other nondestructive tests.
Several types of optical instruments are used during the specific 'optical inspection' technique. These are, *magnifying lenses, borescopes, micro-borescopes, flexible fiber optic borescopes, microelectronic video borescopes & diffracted light* etc.
Magnifying devices and lighting aids are used to detect general area for cleanliness, presence of foreign objects, security of the component, corrosion and cracks or other damages.
In maintenance program Borescope inspections are reducing or eliminating the need for costly teardowns.
In this paper details description of 'various optical devices' and their application techniques in different areas of aircraft structure and engines will be highlighted.

Introduction: The human eye is an important element for performing visual nondestructive tests. But in many cases the human eye is not sensitive enough or cannot access the test site. As a part of maintenance program and to ensure the safety and structural integrity of aircraft, 'Optically aided visual methods' are frequently used, where access is poor for other nondestructive tests. Such tests includes the magnifiers and borescopes
Devices for viewing the interior of objects are called *endoscopes,* from the Greek words for ' inside view'. Industrial endoscopes are called *borescopes* because they are generally used in machined apertures and holes.
Probably in1946, an ultraviolet light borescope was developed for fluorescent testing of the interior of hollow steel propeller blades of aircraft engine. The 100W-viewing instrument detected interior surface discontinuities as glowing green lines. Later in 1958 the USAF B-47 Bomber fleet was grounded because of metal fatigue cracks resulting from low-level simulated bombing missions. Visual testing with borescopes was proved the effective method for the first step to resolve the problem. In 1950s, a system was developed for automatic testing of helicopter blades. The borescope supported by long bench could test the blades while the operator viewed results on a television screen. In 1960s Mr. Lang developed the radiation optics in a project to keep functional the borescope system in high temperature environment. He also pioneers the use of closed circuit television with borescopes for testing the inner parts of jet engines and wings, hollow helicopter blades and nuclear reactors. In 1965 a borescope was invented whose mirror could precisely controlled and this borescope could zoom to high magnification and could intensely illuminate the walls of chamber by means of a quartz incandescent lamp containing iodine vapor.
Since then various optical devices are using during aircraft maintenance.

Inspection devices: Some optically aided visual test devices are described below in brief.
1.Magnifying lenses 2.Borescopes 3.Microelectronic Video Borescopes 4. Diffracted light
1.Magnifying lenses: An optical microscope is a combination of lenses used to magnify an image. The object is placed close to the lens in order to obtain as great a magnification as desired. The distance from lens to object is adjusted until the object is in the lens's depth of field and is in focus. The field of view is the area seen through the magnifier. With a simple magnifier, the diameter of the field of view is less than its focal length. So selection of a magnifier with the proper field of view is important.

2.Borescopes: Borescope is a precise optical instrument with built-in illumination. It can be used to visually check internal areas deep holes, bores and tubes.

Borescopes are available in *rigid* and *flexible* models from 2.00mm in diameter to 19mm in diameter and several feet in length. Several types of Borescopes are shown in ***Figure-1*** and ***Figure-2.***

i) Rigid Borescopes: (a) A rigid Borescope has a metal tube containing a series of lenses, which provide a view of the inspection area, and a lighting system that directs light to the inspection area.

(b) Rigid Borescopes are available in sizes ranging from approximately 2.0 mm [O.08 in] in diameter and a few centimeters in length, to approximately 19.0 mm [O.75 in.] in diameter and many centimeters in length.

(c)Borescopes can be supplied with optical systems, which will provide direct, right angle, rear and fore oblique directions of view.

(d) Many borescopes have an adaptor on the eyepiece, which allows the image of the inspection area to be recorded on photographic film, on video, or to be viewed with a Closed Circuit TV System (CCTV).

(e) Borescopes usually have high image resolution and a depth of field, ranging from a few millimeters (fractions of an inch) to infinity.

(f) Rigid borescopes are available with various magnification powers and adjustable focus controls.

ii) Flexible Borescopes: (a) Flexible Borescopes are armoured plastic tubes, which can be manipulated into various curves and angles thus permitting access to areas, which are inaccessible to rigid borescopes. They are also available in various diameter/length combinations.

(b) These borescopes do not have an intermediate lens system within the flexible tube. At each end of the tube is a Lens system connected by two bundles of glass fibers. The outer bundle of fibers transmits light to the inspection area whilst the inner bundle transmits the image of the inspection area to the Lens in the eyepiece. The lighting is usually provided by an external, variable intensity, cold light source. At the eyepiece there is a focusing ring that permits adjustment of image clarity.

(c) Flexible borescopes may have replacement object lenses, which provide a change of the angle, or field, of view. Some borescopes have a knob, near the eyepiece, which controls a steerable tip (distal end). This control permits changes of angle of view and allows the distal end to be steered past obstructions.

(d) The image resolution of flexible borescopes is, generally, lower than that of rigid borescopes.

(e) Where access is difficult, it may be necessary to use guide tubes to enable the borescope to be directed to the inspection area. Details of guide tube requirements would be stated in the specific nondestructive testing manual for procedure.

(f) Adaptors are also available to enable the image of the inspection area to be recorded on photographic film, on video, or to be viewed with a CCTV system.

3.Microelectronic Video Borescopes: An electronic sensor embedded in the movable tip of the probe transmits signals to video processor, where the image is sent to monitor. The video borescope has a bright, high resolution color image with no distortion or spots. The device does not have an eyepiece like other borescopes. It has freeze frame feature that allows closer viewing of the image. The image can be electronically transferred for permanent documentation.

The image may be magnified for precise viewing. The field of view is up to 90 degrees and the probe tip has four-way articulation.

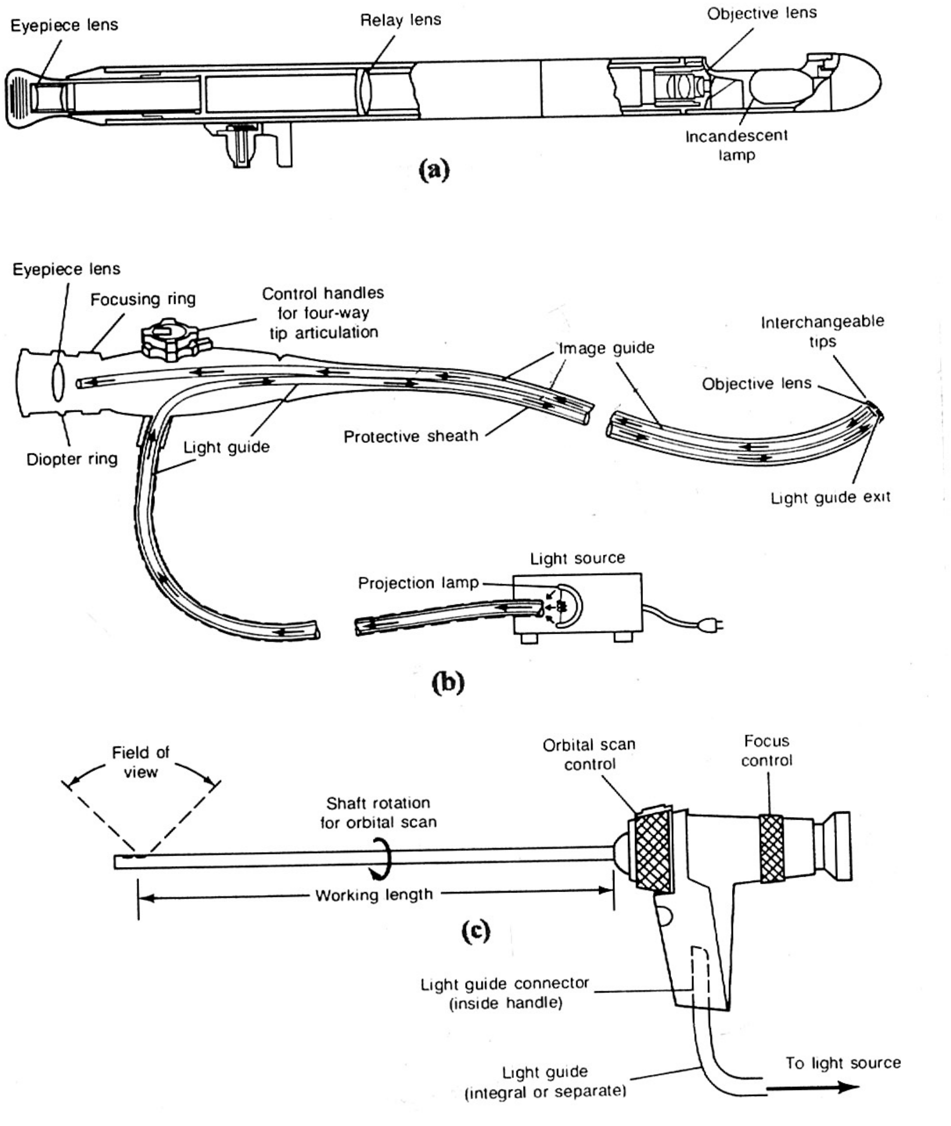
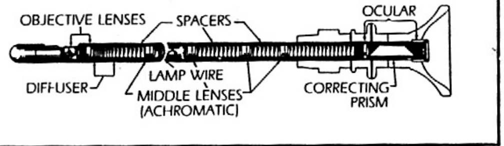


FIGURE-1

Three typical designs of Borescopes (a) A rigid borescope with a lamp at the distal end b) A flexible fiberscope with a light source (c) A rigid borescope with a light guide bundle in the shaft

FIGURE-2 Sectional view of a typical borescope, showing relationship of parts in its optical system



4.Diffracted light: A technique using diffracted light has been developed for visualizing surface distortions, depression, or protrusions as small as 10 µm (0.39mil). A real time technique particularly applicable to rapid inspection of large surfaces. The national research council of Canada suggested using this technique to inspect composite structures for barely visible impact damage. The optical setup for the diffracted light technique consists of a light source, a retroreflective screen, and the object being inspected. The surface being inspected must be reflective. Both flat and moderately curved surfaces can be inspected using this method.

Applications: Followings are some applications of 'optical devices' on aircraft structure and engines.
Aircraft
Torsion Bar Core Corrosion Pitting: Stress corrosion cracks can cause failure in high strength steel spoiler torsion bars. Investigation revealed 'corrosion pitting' on the inside surface of the torsion bar cavity (bore) was found to have led to stress corrosion cracks and subsequent failure. For this inspection 70 or 90-degree borescopes are used.

Slat drive mechanism bell crank: The operator reported several slat bell crank failures. Investigation revealed that failures were caused by fatigue cracks that initiated at the bell crank-to-collar attachment holes. With the bell crank installed on the aircraft, access to the crack area is extremely poor, preventing the ultrasonic, eddy current or radiographic testing .This leaves the fiber optic borescope as the only option for inspecting the this component. A rigid right angle flexible borescope with defecting tip 5-mm diameter and about 1 meter in length is generally used for this inspection.

Spoiler actuator Mechanism Lube Holes: Failures of the link or fitting assemblies of the slat drive mechanism were found to be caused by fatigue cracks generated at the inner surface of the lubrication holes in the link and fitting assemblies. After removing the lubrication fittings and grease visual inspection carried out with a 70-degree forward oblique borescope, 2.7mm in diameter by 180mm length. Crack indications are sought at the inboard and outboard sides of the lubrication bore.
Wing Rear spar doubler and web under trapezoidal fitting: Fatigue cracks may occur in the wing rear spar cap web and doubler under trapezoidal panel attachment fitting. These fatigue cracks may occur in both the web and doubler or in each member separately. The cracks originate at the lower edge of both members. Direct access to the cracked areas of the web and doubler require removal of the trapezoidal fitting. Other methods of NDT cannot be used due to poor access caused by the fitting. The visual test can be done with optically aided O degree borescope along with a 70 to 90 degree borescope, 300 to 480 mm in length and 4 to 5mm in diameter.
Rudder Rib Flange: Cracks develop in the rib flanges of the rudder and investigation revealed that the said cracks resulted from acoustically induced vibration. It was also determined that installation of stiffeners to on the rudder ribs strengthens the rudder and minimizes the possibility of further crack development. A radiograph test is first conducted and if cracks are detected in the rib flanges at or adjacent to the skin attachment fastener holes, their lengths must be determined. Their lengths may be difficult to determine from radiographs alone. If cracks occur within or progress into the flange upper radius, their lengths must be determined by use of 3.2 mm (0.125 inch) diameter rigid borescope or flexible borescope of 'O' degree.

Main landing gear truck beam: Several instances of 'main landing gear truck beam assembly' failures were reported as resulting in major secondary damage to the aircraft. Investigation revealed that failure was a result of stress corrosion fracture that initiated at or immediately adjacent to the intersection of the lubrication hole and the pivot bore.
The stress corrosion fracture is result of severe pitting in the lubrication hole caused by inadequate lubrication.
If this condition is not corrected in time, the truck beam assemblies are vulnerable to failure. Removing corrosion or pitting from the surface of the four pivots bore lubrication holes and increasing the frequency of lubrication minimizes the possibility of failure and extends the service life of the beam assemblies.
The internal surface of each bore is inspected using 'O' degree 0.110-inch diameter and 0.110 inch diameter 70-degree borescopes.

Wing Front spar lower cap: The purpose of this test is to check the lower spar cap forwarding fatigue cracks at the fastener locations. The area of interest is located at the wing pylons that support the jet engines. In addition to other NDT techniques borescopes inspection is also done to check the abnormalities of fasteners located under the fitting. Inspection of fasteners of inboard side fitting is done using a flexible borescope with minimum length of 2 feet. The area under the footstool fitting is inspected using flexible or rigid 90-degree borescope. With this inspection it has proven to detect small cracks at the forward and aft side of the fasteners and larger cracks that propagate to the leading edge [fwd] or vertical leg [aft] of the cap.

Engine

To make an effective airworthy inspection, different internal areas of engines are required on wing borescope inspection at certain interval.

Following areas of CF6-50 turbofan engines are periodically inspected.

1.Fan section: 2.Compressor section 3.Combustor Section 4. High-pressure turbine section 5. Turbine mid frame 6. Low-pressure turbine

1.Fan section: Considering the Engine problem 1st stage & 2nd stages of fan rotors are generally visually inspected through the engine inlet.

As per CF6-50 NDTM borescope inspection frequently required to check at 3rd and 4th Stages fan rotor blades. During the inspection following defects are to be recorded.

i) Cracks or Tears ii) Nicks & Scratches iii) Dents iv) Erosion v) Tip Curl vi) Pits vii) Distortion leading or trailing edges viii) Missing metal.

The primary Borescope used for fan blade inspection is the wide angle (60-65 degree) 'field of probe'.

2.Compressor section: Borescope inspection carried out at compressor section [14 stage rotor blades] with either the rigid or flexible fiber optic system. The following defects are sought during inspection i) cracks at airfoil & tips ii) tears iii) leading and trailing edge damage iv) foreign object damage (FOD) domestic object damage cause random impact throughout the high-pressure compressor rotor stages.iv] tip curl v) missing metal [airfoil] vi) airfoil surface defects vi) blade tip damage vii) corrosion and dirt viii) airfoil erosion, platform distortion, bowing and shingling, aluminum deposits.

3.Combustor Section: Combustor assembly inspection may be accomplished with either the focusing borescope system or the rigid optic fiber light type borescope system. The 60-degree field with 5.5mm to 6mm outer diameter probes is used for this inspection. The high intensity light source is used for this specific area inspection.

During on wing inspection following defects are sought discoloration, carbon accumulation, riveted joints defects, dome bands/plates defects, igniter tubes and ferrule defects, inner &outer liner assemblies defects, missing metals &burn- through, distortion or bowing of the liner assemblies.

4.High pressure turbine section: Borescope inspection of the High pressure turbine nozzle inspection at stage-1 is done by rigid and flexible borescope to find nozzle radial & axial cracking, craze cracking, Nicks, scores, scratches/dents, cracks in airfoil fillet at platform, Metal splatter etc. and defects at turbine rotor section.

5.Turbine mid frame area**:** Turbine mid frame section inspection required on condition engine maintenance plan. Both rigid and flexible borescopes used to check the said area.

6.Low-pressure turbine**:** Low-pressure turbine rotor stages are inspecting by both rigid & flexible borescopes with greater magnification. In questionable circumstances regarding defect identification various angles and variable light levels probes are used.

Conclusions: Optically aided visual testing is a viable and economical method to monitor the structural integrity of in-service aircraft. Even when other nondestructive techniques are used to detect surface cracks, visual inspection with optical aids often provides a useful supplement. The basic design of the borescope has been in use for many decades and it continues to develop, accommodating advances in video illumination, robotic and computer technologies. With the advancement of various optical devices the area of applications are getting wider during maintenance activities of aircraft.

References: i) Visual and optical testing Vol-8 ASNT ii) GE CF6-50 engine manual iii) ASM Handbook Vol-17 Nondestructive evaluation & Quality control.