

A System And Method For Inspecting A Joint Between Components Of An Aircraft

Field of the Invention

The invention relates broadly to a system and method for inspecting a joint between
5 components of an aircraft.

Background

Critical structures, such as the wing-to-fuselage joint of an aircraft need to undergo
periodic inspection. Preferably, a non-destructive inspection (NDI) as specified by the
10 manufacturer or an airworthiness authority is used. NDI is important to maintain the
structural integrity and safety of an aircraft. Possible NDI techniques include
radiography, or X-ray.

An aircraft may utilise a number of fasteners, such as bolts or rivets to secure the
15 fuselage to ribs provided on the wings. These fasteners are subjected to high stress
which may, in the long run, lead to fatigue cracking of areas around the fastening holes.
A recommended NDI method to detect these cracks utilises X-ray.

Presently, X-ray inspection methods with X-ray films are used. The pre-inspection
20 preparation, and the actual inspection procedure of presently used X-ray inspection
methods are laborious. Due to complexity in the construction of wing-to-fuselage joint, in
order to inspect a wing structure around the fasteners, an X-ray source is manually
placed above a designated fastening area, from inside the passenger cabin. Thereafter,
an NDI technician crawls into a confined portion of a center wing fuel tank and after
25 positioning an X-ray film directly below the designated fastening area, exit the fuel tank.
Again, after an X-ray exposure, the NDI technicians need to re-enter the fuel tank to
retrieve the exposed film. Since each designated area has hundreds of fasteners, the
entire cycle need to be repeated several times to complete the inspection process.

30 As numerous exposures are required, the NDI technicians enter and exit the fuel tank
several times. For instance, to inspect a Boeing 747 aircraft, a technician may need to
enter and exit more than one hundred times. Technicians working two shifts may require
11 nights to complete the inspection of all the fasteners in the center wing fuel tank. In
addition, considerable amount of time is required to develop and interpret the films.
35 Furthermore, should any of the exposed film images prove unsatisfactory or show

suspicious details associated with potential cracks, a re-exposure must be made, which, in turn, increases the inspection time.

There is a need for a method and system for inspecting the center wing fuel tank of an aircraft which seeks to address one or more of the above problems.

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Summary of the invention

According to a first aspect of the present invention, there is provided a system for inspecting a joint between components of an aircraft, the system comprising:

a conveyable X-ray source;

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a conveyable digital X-ray detector;

a control unit for remotely controlling movement of the X-ray source and the digital detector such that the X-ray detector and the X-ray source are aligned across a segment of the joint and for remotely controlling capturing of an X-ray image of the joint for identifying defects in the joint.

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The X-ray source, the digital detector or both may be mounted on respective remotely operated vehicles (ROVs). The ROVs may be track mounted.

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Preferably, a first track for a first ROV to which the X-ray source may be is mounted may be removably fixed along a cabin floor. The first track may be removably fixed at existing points for fixing passenger seats of the aircraft. The first removably mounted track may be segmented.

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Preferably, a second track for a second ROV to which the digital X-ray detector is mounted may be removably supported on tripod struts placed inside a fuel tank of the aircraft.

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The second track may pass through openings in fuel tank baffles between compartments of the fuel tank for forming a track network inside the fuel tank. The second track may be segmented.

The X-ray source may comprise a first manipulator remotely operable to move in multiple axes for fine-positioning of the X-ray source around the joint segment.

The digital X-ray detector may comprise a second manipulator remotely operable to move in one or more axes for fine-positioning of the digital X-ray detector around the joint segment.

5 The second manipulator may comprise telescopically retractable first and second platforms that are connected together by a plurality of connecting members. The second platform may further comprise a support for an X-ray detector plate, the support being moveable in one or more rotational axes.

10 The X-ray source and the digital X-ray detector may each comprise a sensor coupled to the control unit for remotely identifying the locations of the X-ray source and digital X-ray detector.

The system may further comprise a processor for executing an algorithm for processing
15 the captured X-ray images to identify cracks in the joint. Preferably, the algorithm may comprise an edge detection algorithm.

According to a second aspect of the present invention, there is provided a method for inspecting a joint between components of an aircraft, the method comprising the steps
20 of:

providing a conveyable X-ray source;
providing a conveyable digital X-ray detector;
remotely controlling movement of the X-ray source and the digital detector such
that the X-ray detector and the X-ray source are aligned across a segment of the joint;
25 capturing an X-ray image of the joint segment for identifying defects in the joint.

In the above method, the X-ray source, the digital detector or both may be mounted on respective remotely operated vehicles (ROVs). In the above method, the ROVs may be track mounted.

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In the above method, a first track for a first ROV to which the X-ray source is mounted may be removably fixed along a cabin floor. In the above method, the first track may be removably fixed at existing points for fixing passenger seats of the aircraft. In the above method, the first removably mounted track may be segmented.

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In the above method, a second track for a second ROV to which the digital X-ray detector is mounted may be removably supported on tripod struts placed inside a fuel tank of the aircraft. In the above method, the second track may pass through openings in fuel tank baffles between compartments of the fuel tank for forming a track network inside the fuel tank. In the above method, the second track may be segmented.

The above method may further comprise remotely manipulating the X-ray source in multiple axes for fine-positioning of the X-ray source around the joint segment.

The above method may further comprise remotely manipulating the digital X-ray detector to move in one or more axes for fine-positioning of the digital X-ray detector around the joint segment.

The above method may further comprise remotely moving a support for an X-ray detector plate in one or more rotational axes.

In the above method, the X-ray source and the digital X-ray detector may each comprise a sensor coupled to the control unit for remotely identifying the locations of the X-ray source and digital X-ray detector.

The above method may further comprise executing an algorithm for processing the captured X-ray images to identify cracks in the joint.

In the above method, the algorithm may preferably comprise an edge detection algorithm.

Brief description of the drawings

The invention is further described by way of non-limiting examples, with reference to the accompanying drawings, in which:-

Figure 1 is a cross-sectional view of an aircraft fuselage illustrating a system for inspecting a center wing fuel tank;

Figure 2 is a detailed perspective view of a portion of the aircraft fuselage showing the positioning of an X-ray source above the center wing fuel tank;

Figure 3 is a detailed perspective view, partly in section, of the center wing fuel tank of the aircraft showing the positioning of a digital X-ray detector;

Figure 4 is a detailed view of a portion of a wing-to-fuselage joint of the aircraft with the inspection system of Figure 1;

Figure 5 is a perspective view of a remotely operated vehicle suitable for mounting the digital X-ray detector;

Figure 6A is an example of a raw X-ray image from the digital detector of Figure 5;

Figure 6B is an example of a pre-processed X-ray image of Figure 6A; and

Figure 7 shows a flow chart illustrating a method for inspecting a joint between components of an aircraft.

Detailed description

The described embodiment integrates digital X-ray technology with remotely operated vehicles (ROVs) and use an automatic defect recognition (ADR) algorithm in identifying potential defects. The embodiment can speed up the center wing tank inspection process.

Digital X-ray detectors eliminate the need for film thereby allowing instant availability of results, while the automation process significantly reduces the number of instances a technician needs to enter or exit the center wing fuel tank, which, in turn, helps in faster interpretation of results.

The described embodiment may assist in reducing the total inspection time. For instance, the inspection time for a Boeing 747 aircraft is reduced from the present 11 nights to an estimated 2 nights. This may be achieved through the immediate availability of X-ray images using digital detectors and reducing the number of instances a technician need to enter or exit the center wing fuel tank, for example, to just two. In addition, the described embodiment can eliminate the need to re-inspect at a later stage. Any suspicious details of images from the digital detector can be instantly analysed by the ADR algorithm. If in doubt, the technicians can instantly command the remotely operated vehicles to re-inspect the relevant area and confirm the validity of defect.

Figure 1 is a cross-sectional view of an aircraft fuselage 150 illustrating an inspection system 100 in accordance with the example embodiment.

5 The inspection system 100 consists of an X-ray source 102, a digital detector 104, a positioning system for the X-ray source 102 in the form of a first track-mounted ROV 103, a positioning system for the digital detector in the form of a second track-mounted ROV 105, and a computer system 183 for controlling the two ROVs 103, 105 and the X-ray source 102 and digital detector 104 and for executing an automatic defect
10 recognition (ADR) algorithm in identifying defects. The computer system 183 can be coupled to the ROVs 103, 105 and the X-ray source 102 and the digital detector 104 through wire connections, or in a wireless fashion.

A power supply 140 is provided and located inside the aircraft for supplying power to the
15 ROVs 103, 105 and the X-ray source 102 and the digital detector 104 through cable connections (not shown). A dispensing/routing mechanism 187 is utilized for the power/data cables 189 to prevent fouling or entanglement inside the fuel tank 109.

Preferably, the dispensing/routing mechanism 187 may be a drum-type mechanism
20 located outside the aircraft and the cable 189 may be dispensed or reeled in and out depending on the location of the ROV 105. Preferably, the power/data cables 189 may be guided by a trough or slot within a track 115 of the second ROV 105 and lined with low-friction material, such as Teflon. In addition, restraints may be provided on the track 115 to prevent the cables 189 from popping out of the guided trough or slot.

25 The X-ray source 102 is a commercially available X-ray tube e.g. a fully Commercial Off The Shelf (COTS) tube or any suitable tube meeting the required power and focal spot size (sensitivity).

30 The digital detector 104 is also a COTS-technology detector, but customized and repackaged so as to fit into confined recesses of an aircraft during inspection. The digital detector 104 in the system 100 is repackaged in order to reduce the size of an active area from 16 inches x 16 inches (40.64cm x 40.64cm) in a typical detector to one that is approximately 4 inches x 5 inches (10.16cm x 12.7cm). Active area refers to an area on
35 the digital detector 104 having scintillator material used in converting X-ray energy into light energy.

For illustration, the passenger cabin 107 is mounted with passenger seats 111 only on one side of the cabin floor 101. The other side of the cabin floor 101 is shown without passenger seats 111. A first track 112 is removably fixed along the longitudinal axis of the cabin floor 101, on points provided for fixing the passenger seats 111. An X-ray tube 102 is mounted on the first ROV 103, which, in turn, is mounted on the first track 112. In use, the first ROV 103 moves over the first track 112.

The digital detector 104 is mounted on the second ROV 105, which, in turn, is mounted on a second track 115 in the fuel tank 109. In use, the second ROV 105 moves over the second track 115.

The first ROV 103 has a 3-axis positioning capability (i.e. operable to move in the directions of 250, 260 and 270) so as to position the X-ray tube 102 over an area near the wing-to-fuselage joint in the passenger cabin 107.

Figure 2 is a detailed perspective view of a portion 200 of the aircraft 150 showing the positioning of the X-ray source 102 above the center wing fuel tank 109. The cabin floor 101 is shown in section to view the inner details of the fuel tank 109. The first ROV 103 is mounted on the elongate first track 112 located inside the passenger cabin 107. The first track 112 is removably mounted on the cabin floor 101 in a direction parallel to the longitudinal axis 260 of the passenger cabin 107, beneath the aircraft windows 211.

The center wing fuel tank 109 in Figure 2 has side walls 203 and a plurality of compartments 215. A plurality of baffles 209 separate the compartments 215. The baffles 209 limit the sloshing of fuel in the fuel tank 109 when the aircraft is in motion. Each of the baffles 209 has an opening 213 through which the second track mounted ROV 105 (not shown) passes to neighbouring fuel tank compartments 215 during inspection.

Figure 3 is a detailed perspective view of a portion 300 of the center wing fuel tank 109 showing the positioning of the X-ray detector 104 mounted on the second ROV 105. The second ROV 105 moves on the second track 115, inside the center wing fuel tank 109. The second track 115 is removably mounted on the base 317 of the fuel tank 109. The second track 115 comprises a network of track segments with pre-determined dimensions and rests on a plurality of tripod struts or stanchions 305. The tripod struts or stanchions 305 rest on the base 317 of the fuel tank 300. Each of the baffles 209 has

one or more openings 213 through which the second track 115 passes in forming the track network.

Initially, the second ROV 105 is positioned at one end 320 on the second track 115 and enters into a first fuel compartment 215 through the opening 213 in the baffle 209. Thereafter, the second ROV 105 can move in the horizontal axes 260 and 270 by being moved on the track network inside the fuel tank 109. In addition, the second ROV 105 is operable to rotate in two rotational axes.

During the pre-inspection setup, technicians carrying the disassembled second track 115 and tripod struts or stanchions 305, climb into a first compartment 266 at one end of the fuel tank 109 and proceed to the aft-most compartments 252 and 254. After laying the second track 115 and tripod struts or stanchions 305 in compartments 252 and 254, they withdraw and repeat the process in the adjacent compartments 256, 258, 262, 264 and 266 sequentially, in the direction of 260. The second ROV 105 is then placed on the second track 115 and the movements are controlled by the computer 183 (Figure 1).

Returning back to Figure 1, The first ROV 103 is a customised wheeled vehicle on which the X-ray tube 102 is mounted on a 3-axis translational positioning manipulator that is operable to move the X-ray tube 102 around structural obstructions and fine-position the X-ray tube 102 above an area to be inspected. The first track 112 is segmented and of a quick snap-together or quick release type (akin to toy train tracks). The first track 112 is removably attached to those points that are typically used to mount the passenger seats 111 on the cabin floor 101.

The second ROV 105 carrying the digital detector 104 is also a customised wheeled vehicle having a 3-axis translational and 2-axis rotational positioning capability and operable to move the digital detector 104 around structural obstructions, and fine-position the detector 104 below a fastening area of a wing-to-fuselage joint. As the second ROV 105 passes through dimensionally restricted access holes 213 of the baffles 209, a folding mechanism is used to allow the second ROV 105 to be dimensionally compact, and yet have the ability to access the entire area of the fuel tank 109.

The second track 115 is removably fixed inside the fuel tank compartment 109. The second track 115 is segmented and of quick snap-together or quick release type. It is

distinctively marked in order to facilitate quick placement within the fuel tank 109. The second track 115 is supported by telescopic tripod struts or stanchions 305 (Figure 3) which are stowed for easy carriage and pre-set to extend to various lengths and heights within the fuel tank 109.

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Both the first ROV 103 and second ROV 105 in the example embodiment are remotely controlled by an operator in a control room 180. The computer system 183 is operable to control and coordinate the operation of the X-ray source 102 and digital detector 104 as well as of the first ROV 103 and the second ROV 105.

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In order to perform inspection of the fuel tank 109, an operator operating the computer system 183 from the control room 180 remotely commands the two ROVs 103, 105 to move toward a designated area around fasteners that is to be inspected. The X-ray tube 102 and digital detector 104 are then powered on, and a digital scanned image of the designated area appears on an operator console 185. The operator fine-positions the X-ray tube 102 and detector 104 until an optimum image is obtained. The scanned images are recorded in a memory storage unit of the computer 180. The recorded images are analysed by executing an automatic defect recognition ADR algorithm stored in the computer 180 for identifying potential defects. The operator continues to remotely command the ROVs 103, 105 to move on to the next inspection area until all relevant areas are inspected.

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Figure 4 shows a detailed view of a portion 170 of the wing-to-fuselage joint of the aircraft 150, close to the wing 160. The X-ray tube 102 mounted on a manipulator 472 is positioned on top of an area around the fasteners 471. These fasteners 471 attach the wing structure 473 to the fuselage 475 of the aircraft 150. In use, an X-ray beam 477 from the X-ray tube 102 mounted in the cabin 107 impinges on the area around the fasteners 471. The digital detector 104 positioned beneath the cabin floor 101 from inside the fuel tank 109 is operable to detect the X-ray images. Here, a cable 479 supplies power and facilitates data exchange with the computer system 183 (Figure 1). The positions of the X-ray tube 102 and the digital detector 104 are remotely controlled by an operator. Both the X-ray tube 102 and the digital detector 104 are mounted with sensors 470, 478 each of which are remotely coupled to the computer system 183 (Figure 1). These sensors 470, 478 facilitate in identifying the respective locations of the X-ray tube 102 and the digital detector 104.

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Figure 5 is a perspective view of the remotely operated vehicle ROV 105 suitable for mounting the digital detector 104. The ROV 105 is a customized vehicle operable to be manipulated in three translational axes 250, 260, 270 and two rotational axes 557, 559 in order to move the digital detector 104 around structural obstructions, and fine-position the detector 104 below a designated area to be inspected. As the second ROV 105 passes through dimensionally restricted access areas in the fuel tank 109 including the baffles 209, 315, a foldable manipulator 515 is provided.

The foldable manipulator 515 consists of a first platform 503, and a second platform 509. The two platforms 503, 509 are connected together by a plurality of telescopically retractable connectors 505 operable to move in the direction of 250. The first platform has wheels 501 to enable movement of the second ROV 105 on the second track 115. A base 513 is mounted on the second platform 509. The base 513 is operable to move relative to the second platform 509 in the direction of 270. A cylindrical structure 511 is mounted on the base 513. The digital detector 104 moves co-axially over the cylindrical structure 511 in a direction 260. In addition, the digital detector 104 can be move in two rotational axes 557 and 559.

Figure 6A is an example of a raw X-ray image 600 from the digital detector 104. In the example shown, cracks 640 in the wing-to-fuselage area as well as fastening holes 603, 605 of various dimensions are visually seen as images in the operator console 185.

Figure 6B is an example of a pre-processed X-ray image 650 of Figure 6A showing the cracks 640. The raw X-ray images 600 from the digital detector 104 are pre-processed by an existing off-the shelf X-ray system control software whereby the raw X-ray images are subject to contrast adjustments and edge enhancement processing. Pre-processing of raw X-ray images is done to enable the ADR algorithm to have a higher chance of detecting the defects in the aircraft structure.

The pre-processed images 650 are presented in the form of a gray-scale image having many thousands of shades of gray, depending on the capability of the digital detector 104. The image edge-enhancement processing highlights those features (in the raw image 600) that have edges, e.g. the edge of a bolt 471 or a discontinuity in a structure related to the presence of cracks under the bolt heads. Where cracks are present in the structure, more X-rays pass through the structure and impinge on the detector 104.

The computer system 183 (Figure 1) converts these images into a digital image having lighter grey scale against a dark background.

5 Upon detection of a defect, the operator warns a relevant authority to take corrective action.

10 The ADR algorithm executed on the computer 183 (Figure 1) automatically analyses the recorded images 600, 650 and identifies the potential defects. By assisting the technicians in image analysis, the ADR algorithm expedites the inspection process.

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The ADR algorithm used in the inspection system is based on existing edge-detection algorithms that can identify irregularities of a digital radiograph image. The pre-processed X-ray images 650 from the digital detector 104 are further processed by the ADR algorithm. In use, the ADR algorithm can recognise and identify the difference in 15 grey scale images of edges corresponding to discontinuities arising out of potential cracks 640 and that of a bolt head 471 itself. For example, if the ADR algorithm detects that there is a jump in the gray scale from darker to lighter over the span of a few image pixels, it may tag this as a "suspected" defect and highlight the subject image in a distinctive colour so as to catch the operator's attention. If in doubt, a technician can re- 20 inspect the suspected area with greater magnification, or from slightly different angles, and confirm the validity of the defect. The ADR algorithm eliminates the need for the technicians to closely scrutinise every single image as is the case with the existing film-based methods.

25 As the fasteners in the areas to be inspected are typically uniform in size, installed in geometrically similar locations, and the nature of the defects to be detected is typically consistent (e.g. radial cracks 640 emanating from the fastening holes) the inspection method using the ADR algorithm has a higher probability of detection (POD) of defects thereby providing a reliable inspection system.

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Figure 7 shows a flow chart 700 illustrating a method for inspecting a joint between components of an aircraft. At step 702, a conveyable X-ray source is provided. At step 704, a conveyable digital X-ray detector is provided. At step 706, movement of the X-ray source and the digital detector is remotely controlled such that the X-ray detector and the 35 X-ray source are aligned across a segment of the joint. At step 708, an X-ray image of the joint segment is captured for identifying defects in the joint.

It will be appreciated by a person skilled in the art that numerous variations and/or modifications may be made to the present invention as shown in the specific embodiments without departing from the scope of the invention as broadly described.

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For example, it will be appreciated that the described inspection system and method can be adapted to any aircraft with minor modification to lengths/heights of the tracks and fine tuning of the ADR algorithm for optimal performance.

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CLAIMS

1. A system for inspecting a joint between components of an aircraft, the system comprising:

5 a conveyable X-ray source;

a conveyable digital X-ray detector;

a control unit for remotely controlling movement of the X-ray source and the digital detector such that the X-ray detector and the X-ray source are aligned across a segment of the joint and for remotely controlling capturing of an X-ray image of the joint
10 for identifying defects in the joint.

2. The system as claimed in claim 1, wherein the X-ray source, the digital detector or both are mounted on respective remotely operated vehicles (ROVs).

15 3. The system as claimed in claim 2, wherein the ROVs are track mounted.

4. The system as claimed in claim 3, wherein a first track for a first ROV to which the X-ray source is mounted is removably fixed along a cabin floor.

20 5. The system as claimed in claim 4, wherein the first track is removably fixed at existing points for fixing passenger seats of the aircraft.

6. The system as claimed in claim 4, or 5, wherein the first removably mounted track is segmented.

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7. The system as claimed in claimed in any one of claims 3 to 6, wherein a second track for a second ROV to which the digital X-ray detector is mounted is removably supported on tripod struts placed inside a fuel tank of the aircraft.

30 8. The system as claimed in claim 7, wherein the second track passes through openings in fuel tank baffles between compartments of the fuel tank for forming a track network inside the fuel tank.

9. The system as claimed in claim 7, or 8, wherein the second track is segmented.

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10. The system as claimed in any one of the preceding claims, wherein the X-ray source comprises a first manipulator remotely operable to move in multiple axes for fine-positioning of the X-ray source around the joint segment.

5 11 The system as claimed in any one of the preceding claims, wherein the digital X-ray detector comprises a second manipulator remotely operable to move in one or more axes for fine-positioning of the digital X-ray detector around the joint segment.

10 12 The system as claimed in claim 11, wherein the second manipulator comprises telescopically retractable first and second platforms that are connected together by a plurality of connecting members.

15 13 The system as claimed in claim 12, wherein the second platform further comprises a support for an X-ray detector plate, the support being moveable in one or more rotational axes.

20 14 The system as claimed in any one of the preceding claims, wherein said X-ray source and said digital X-ray detector each comprise a sensor coupled to the control unit for remotely identifying the locations of the X-ray source and digital X-ray detector.

25 15 The system as claimed in any one of the preceding claims, further comprising a processor for executing an algorithm for processing the captured X-ray images to identify cracks in the joint.

30 16 The system as claimed in claim 15, wherein the algorithm comprises an edge detection algorithm.

35 17 A method for inspecting a joint between components of an aircraft, the method comprising the steps of:

- 30 providing a conveyable X-ray source;
- providing a conveyable digital X-ray detector;
- remotely controlling movement of the X-ray source and the digital detector such that the X-ray detector and the X-ray source are aligned across a segment of the joint;
- capturing an X-ray image of the joint segment for identifying defects in the joint.

18. The method as claimed in claim 17, wherein the X-ray source, the digital detector or both are mounted on respective remotely operated vehicles (ROVs).

19. The method as claimed in claim 18, wherein the ROVs are track mounted.

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20. The method as claimed in claim 19, wherein a first track for a first ROV to which the X-ray source is mounted is removably fixed along a cabin floor.

21. The method as claimed in claim 20, wherein the first track is removably fixed at existing points for fixing passenger seats of the aircraft.

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22. The method as claimed in any one of claims 20, or 21, wherein the first removably mounted track is segmented.

23. The method as claimed in any one of claims 19 to 22, wherein a second track for a second ROV to which the digital X-ray detector is mounted is removably supported on tripod struts placed inside a fuel tank of the aircraft.

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24. The method as claimed in claim 23, wherein the second track is passed through openings in fuel tank baffles between compartments of the fuel tank for forming a track network inside the fuel tank.

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25. The method as claimed in claim 23, or 24, wherein the second track is segmented.

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26. The method as claimed in any one of claims 17 to 25, further comprising remotely manipulating the X-ray source in multiple axes for fine-positioning of the X-ray source around the joint segment.

27. The method as claimed in any one of claims 17 to 26, further comprising remotely manipulating the digital X-ray detector to move in one or more axes for fine-positioning of the digital X-ray detector around the joint segment.

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28. The method as claimed in claim 27, further comprising remotely moving a support for an X-ray detector plate in one or more rotational axes.

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29. The method as claimed in any one of claims 17 to 28, wherein said X-ray source and said digital X-ray detector each comprise a sensor coupled to the control unit for remotely identifying the locations of the X-ray source and digital X-ray detector.

5 30. The method as claimed in any one of claims 17 to 29, further comprising executing an algorithm for processing the captured X-ray images to identify cracks in the joint.

10 31. The method as claimed in claim 30, wherein the algorithm comprises an edge detection algorithm.