technical note technical note

Shearographic Inspection of a DeHavilland DHC-7

December 1993

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U.S. Department of Transportation
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Technical Center
Atlantic City International Airport, N.J. 08405

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16. Abstract

Under a Cooperative Research and Development Agreement between the Volpe National Transportation Systems Center (VNTSC) and Henson Aviation, Inc., operator of USAir Express, a shearographic demonstration inspection of the fuselage of a DeHavilland DHC-7 aircraft was performed at a USAir repair station at Norfolk, VA, on August 8, 1992. The inspection compared the effectiveness of shearography with currently mandated methods in detecting disbonds in the fuselage. Adhesive bonding is utilized in modern aircraft fuselages, frequently in combination with rivets. As aircraft age, bond failure becomes a major problem, since it may promote fatigue cracking, moisture intrusion, and subsequent corrosion. Any of these events may cause cabin pressure loss and, sometimes, catastrophic fuselage failure. The shearographic method of detecting disbonds depends on the deformation of the aircraft skin under mechanical stimulus. When illuminated by coherent light, the phase relationship and intensity of the light reflected from any two points of the skin changes as a result of this deformation. Surface changes down to 0.00025 millimeter can be detected and displayed as a real-time image of the field of view. Comparison of successive images as the deformation changes permits interpretation of the condition of a bond. In addition, other selected areas of the aircraft suspected to contain disbonds were inspected. No disbonds were found either by shearography or confirming ultrasound readings. Shearography was clearly able to identify the presence of waffle doublers wherever drawings of the aircraft indicated that they should exist. The demonstration indicated potential advantages of shearography over currently used inspection techniques, namely, improved coverage of bonded areas of the fuselage and reduced inspection time of the aircraft.

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EXECUTIVE SUMMARY

Under a Cooperative Research and Development Agreement between the Volpe National Transportation Systems Center and Henson Aviation, Inc., operator of USAir Express, a shearographic demonstration inspection of selected portions of a DeHavilland DHC-7 aircraft fuselage was performed at a USAir repair station in Norfolk, VA, on August 8, 1992. This Technical Note describes the instrumentation and inspection procedure, and presents results. The demonstration indicated potential advantages of shearography over currently used inspection techniques, namely, improved coverage of bonded areas of the fuselage and reduced inspection time of the aircraft.

INTRODUCTION

Adhesive bonding is utilized in modern aircraft fuselages, frequently in combination with rivets. As aircraft age, bond failure becomes a factor, since it may promote fatigue cracking, moisture intrusion, and subsequent corrosion.

In support of the FAA's Aging Aircraft Program, the FAA reviewed candidate nondestructive inspection procedures which might be more reliable than currently mandated techniques, while also reducing the inspection time and associated costs. In order to evaluate these techniques in an operational environment, the Volpe National Transportation Systems Center entered into a Cooperative Research and Development Agreement with USAir, to select, jointly with the air carrier, the most promising technique and to compare its performance with existing methods during routine inspections of aircraft. An earlier study [1] demonstrated that shearography showed considerable promise and concluded that additional demonstrations during other mandated inspections would be desirable. Accordingly, an inspection for disbonds was conducted on a DeHavilland DHC-7 aircraft at the carrier's repair station at Norfolk, VA, on August 8, 1992.

The shearographic method depends on the deformation of the aircraft skin under varying stimulus. When illuminated by coherent light, the phase relationship and intensity of the light reflected from any two points of the skin changes as a result of this deformation. Surface changes down to 0.00025 millimeter can be detected and displayed as a real-time image of the field of view. Comparison of successive images as the stimulus changes permits interpretation of the condition of a bond.

THE AIRCRAFT

The aircraft, a DeHavilland DHC-7, was used in regular service by Henson Aviation and was at Norfolk for routine maintenance. Its service history indicated that it had been previously owned by Air Wisconsin, and that approximately 26,500 flight hours and 36,000 taxi, takeoff and landing cycles had been achieved.

INSTRUMENTATION

Two shearographic systems, owned and operated by Laser Technology, Inc., were employed in the demonstration. The first provided acoustic stimulation as well as fixed focus laser illumination (figure 1). It could be attached directly to the aircraft. The second was a tripod-mounted variable-focus system which could also use acoustic stimulus. For satisfactory use of this instrument, it was necessary to darken the hangar, so as not to interfere with the reflected laser light from the skin surface. The shearograms from both systems were viewed, processed, recorded, and displayed electronically. Specifications of both systems are presented in appendix A.

Figure 1. Shearographic Fixed Focus Illumination System.

INSPECTION PROCEDURE

The inspection was performed in accordance with a procedure jointly prepared by the FAA Technical Center and the Volpe Center (see appendix B). For this demonstration, the right side of the aircraft was inspected from frame X248 and X596 above stringer 20 and below stringer 10. Shearograms were made at discrete locations on the aircraft, which were identified by consulting Body Station Templates listed in the procedure and by referring to the DeH-avilland Structural Repair Manual.

Before setup of the shearography equipment, selected surfaces were spray-painted with dye penetrant developer to increase their reflectivity. Although shearograms may be obtained for untreated surfaces, this increased reflection permitted a larger field of view for a given illuminating power level.

In order to record the field of view covered by a particular shearogram, an image of the illuminated area was initially recorded on videotape. A crayon mark, which corresponded to the upper right-hand corner of this image, was then made on the fuselage to serve as an index point for the next adjacent image. Any anomalies were marked on the skin and the shearogram was also recorded on videotape.

Two methods of straining the fuselage skin were employed. The first was pressurization of the fuselage using the auxiliary power unit. The second was the application of an acoustic stimulus. Examples of the results of these procedures, using the fixed focus system, are shown in figures 2 and 3, respectively. A shearogram obtained with the tripod mounted system using acoustic stimulus is shown in figure 4. The inspection was intended to cover as much of the aircraft as possible during the time available. The fixed focus system could cover an area of about 14x11 inches. As may be seen from figure 4, the variable focus system could cover a considerably larger area.

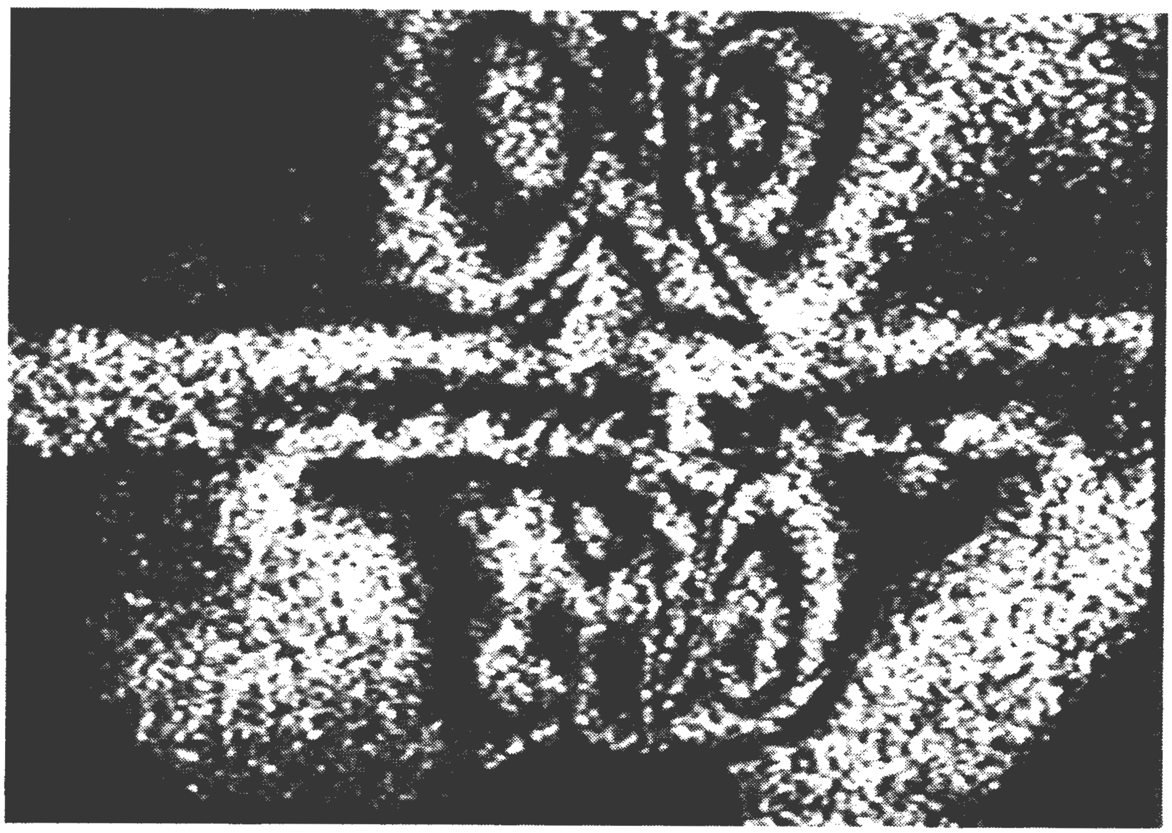

Figure 2. Shearogram of Waffle Doubler using Cabin Pressure Straining.

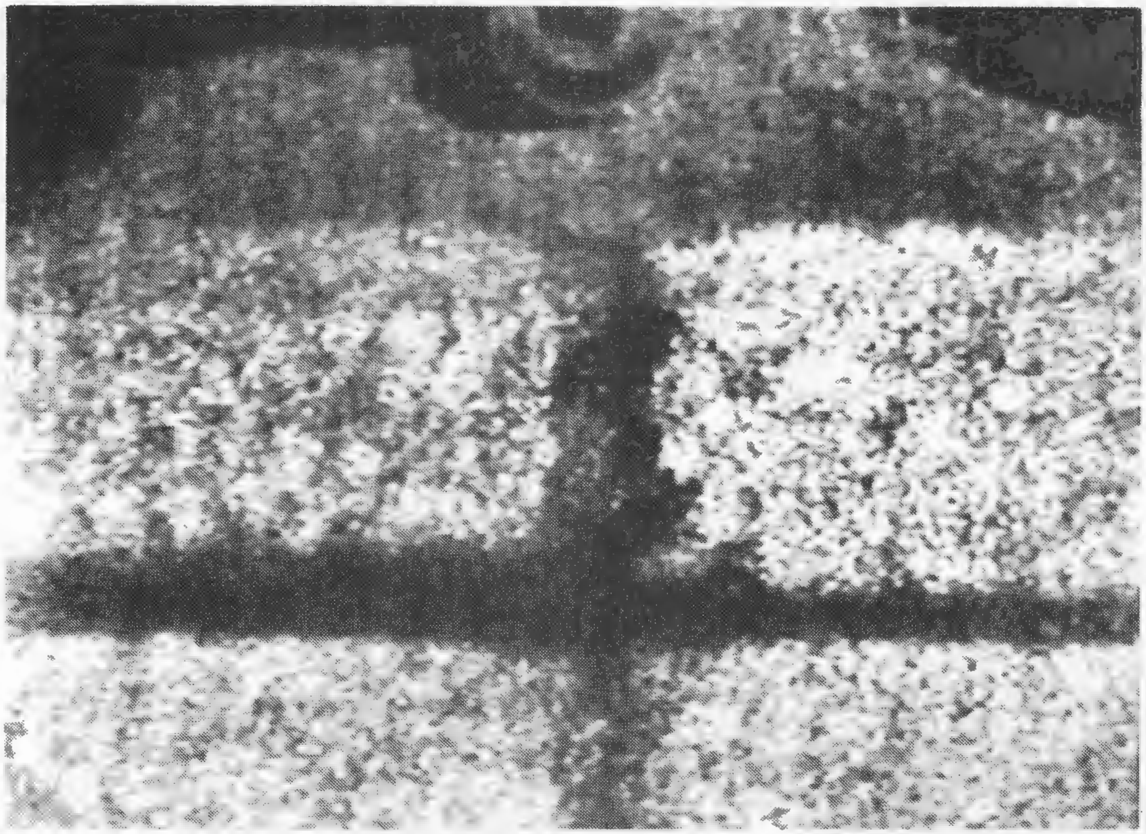

Figure 3. Shearogram of Waffle Doubler using Acoustic Straining.

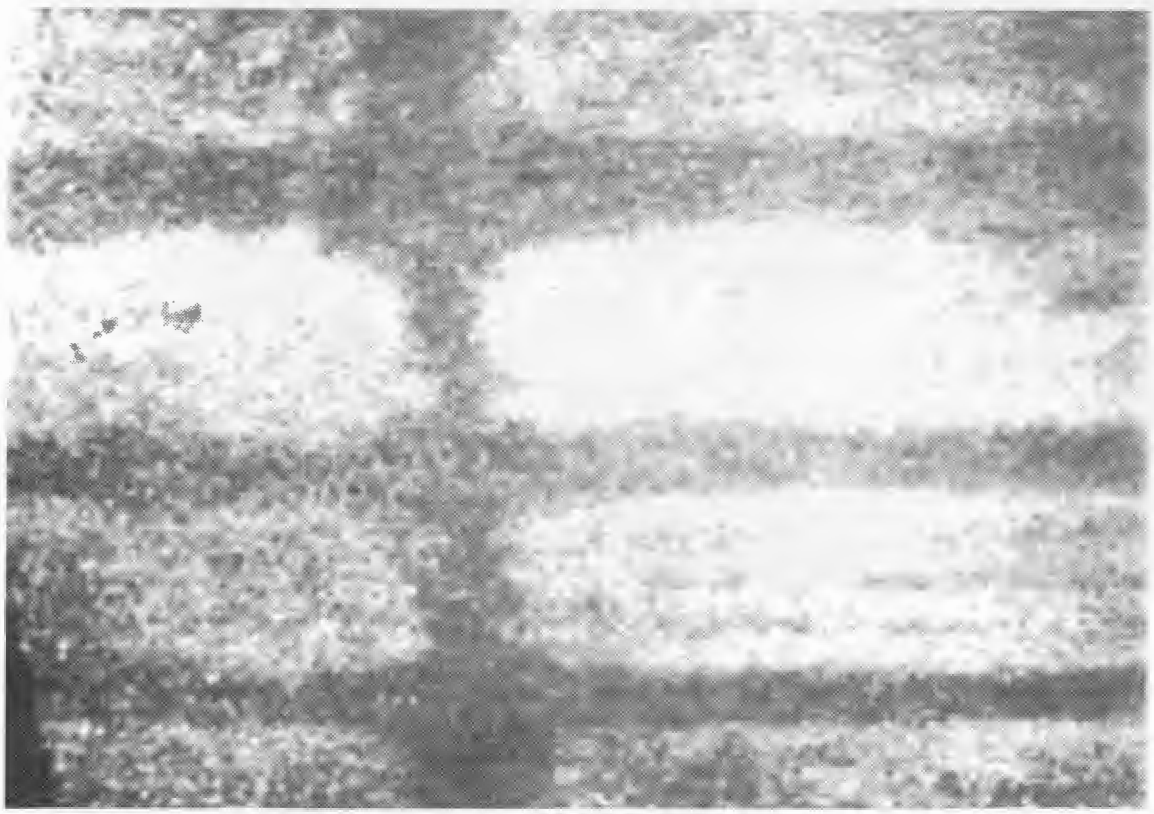

Figure 4. Shearogram from Variable Focus Instrument.

RESULTS

As expected, no disbonds were found in this aircraft, since none had been found by Henson personnel during an inspection in 1990. It should be noted that shearograms image the entire doubler area, whereas, according to Henson inspectors, coverage by ultrasonic instruments is incomplete because of the presence of rivets which render ultrasonic instruments unreliable.

By comparing the shearograms made using pressurization with those using acoustic stimulus, it is apparent that the latter contain fewer fringe lines and are therefore more readily interpreted.

Some problems were apparent when using the tripod-mounted instrument, in addition to those requiring reduction of ambient light referred to earlier. Images were subject to decorrelation (increasing blurriness from small submicron variations in optical pathlength) which quickly degraded image quality. Thus, for a laser of a given intensity, a tradeoff exists between area of coverage and image quality. For the above reasons, the tripod-mounted system needs to be improved to take advantage of the potentially valuable assets of larger area of coverage and greater portability.

Inspection of one half of the pressurized section of the fuselage required approximately one hour, and from the surface covered, it is projected that a complete waffle doubler inspection of the aircraft could be accomplished in four hours. Figures 5 through 8 are examples of shearograms of the waffle doubler configuration found on this aircraft. Figure 5 shows a waffle doubler with cutouts in all four quadrants. Figure 6 shows a waffle doubler with one cutout interrupted by a filled space. Figure 7 shows a doubler with only one cutout. Figure 8 shows the center of a pair of cutouts.

CONCLUSIONS

The principal potential benefits indicated by the demonstration of shearography are greater coverage and reduced aircraft down-time, compared with currently mandated techniques. To make shearography generally applicable and acceptable, it will be necessary to identify applications where the technique will realize a cost benefit and to develop and approve procedures for using it.

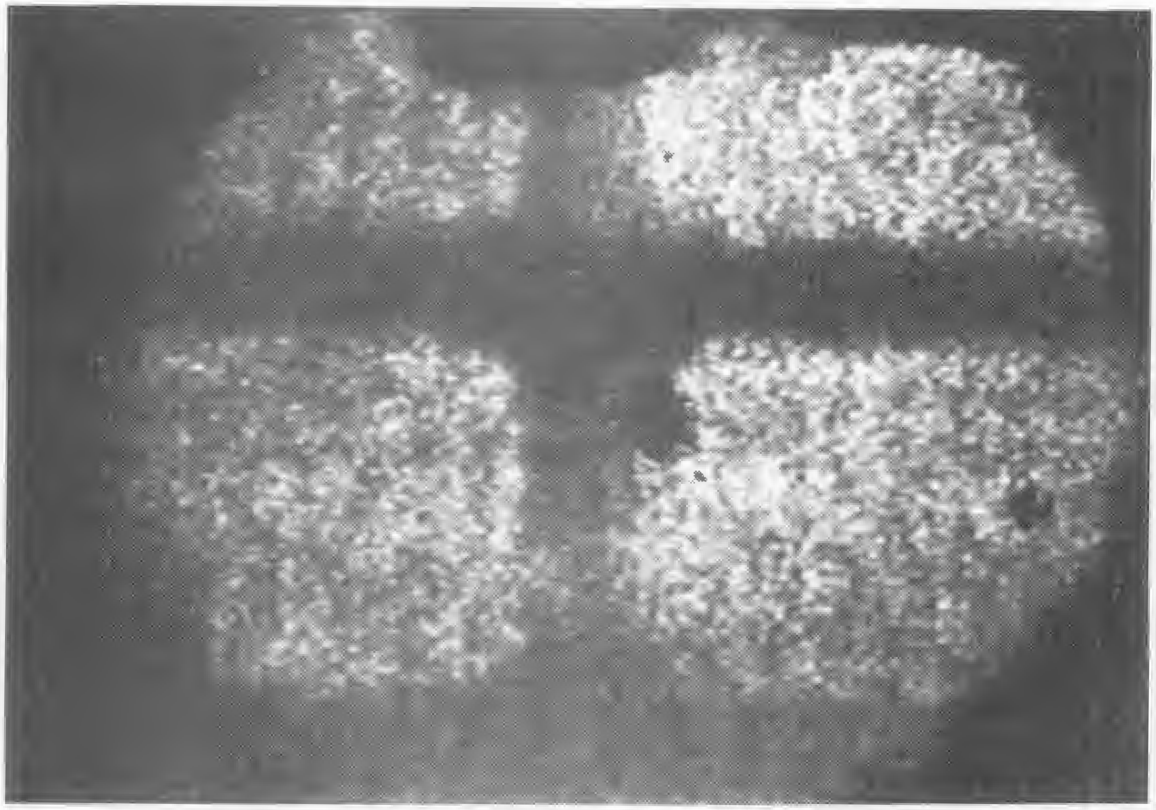

Figure 5. Shearogram of Waffle Doubler, Cutouts in All Four Quadrants (black spots are artifacts from light reflection).

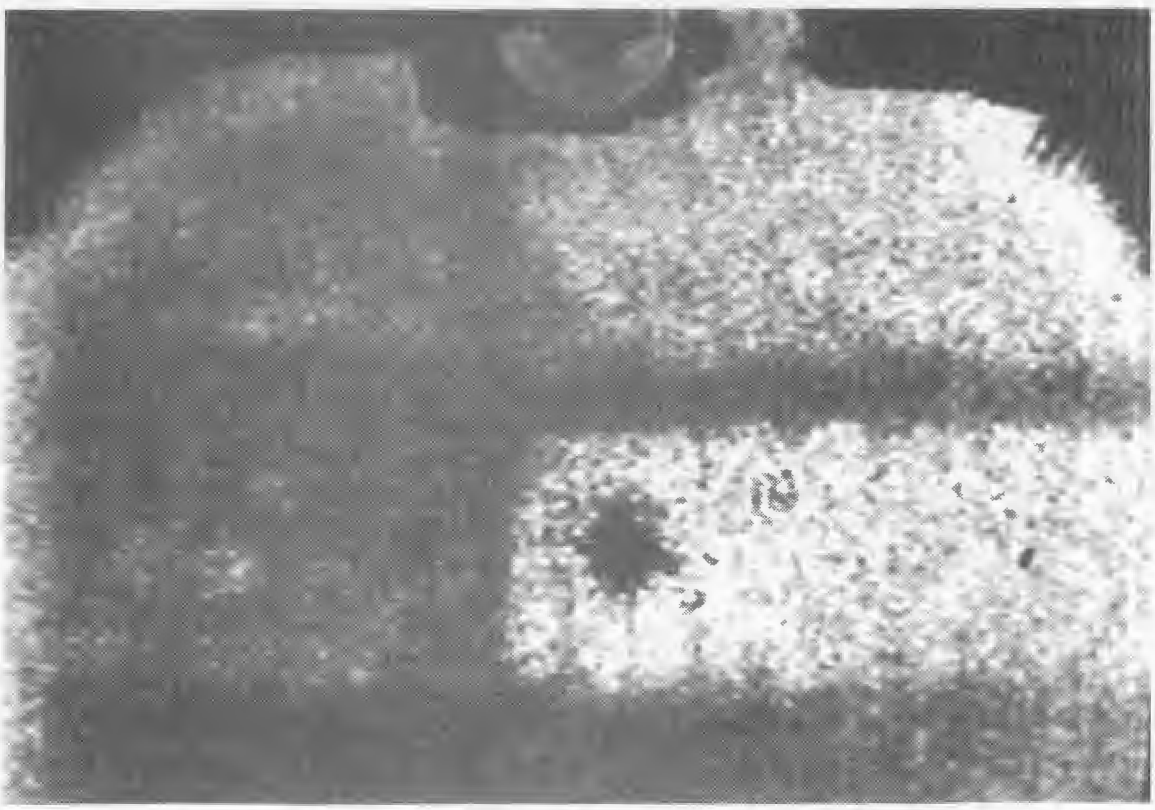

Figure 6. Shearogram of Waffle Doubler with Partial Cutout.

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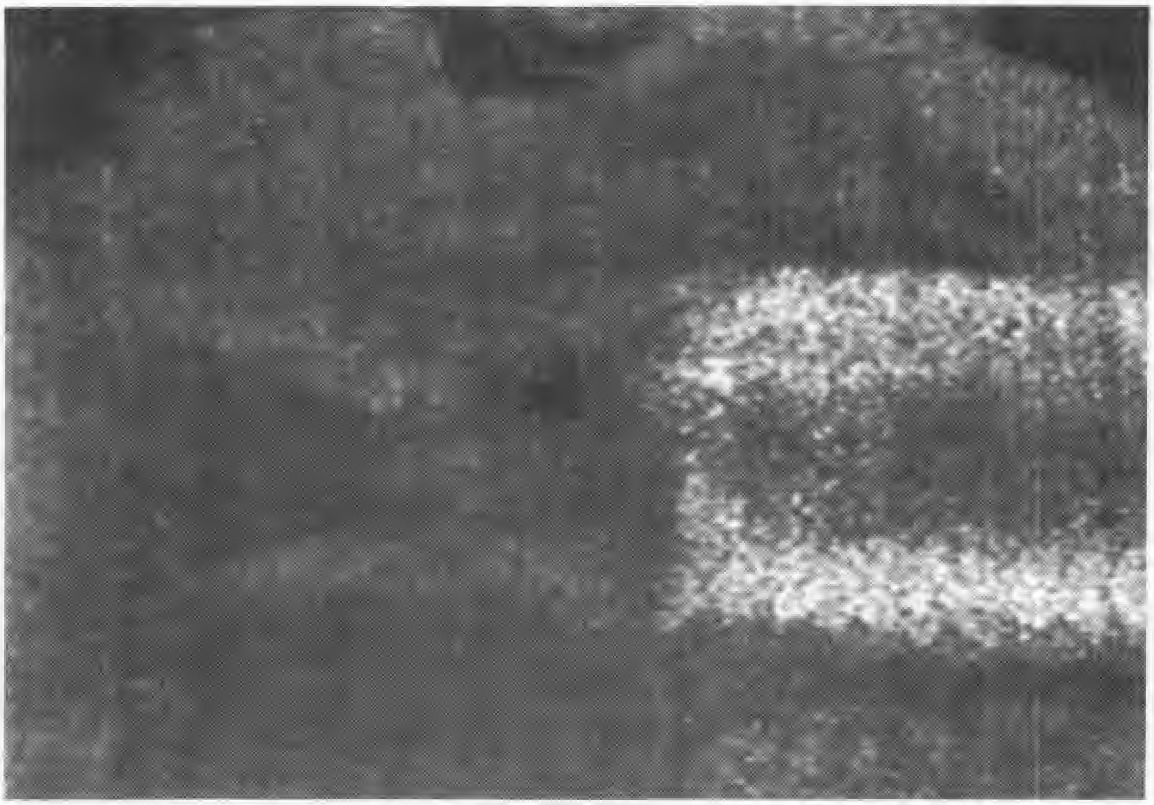
Figure 7. Shearogram of Waffle Doubler with One Cutout.

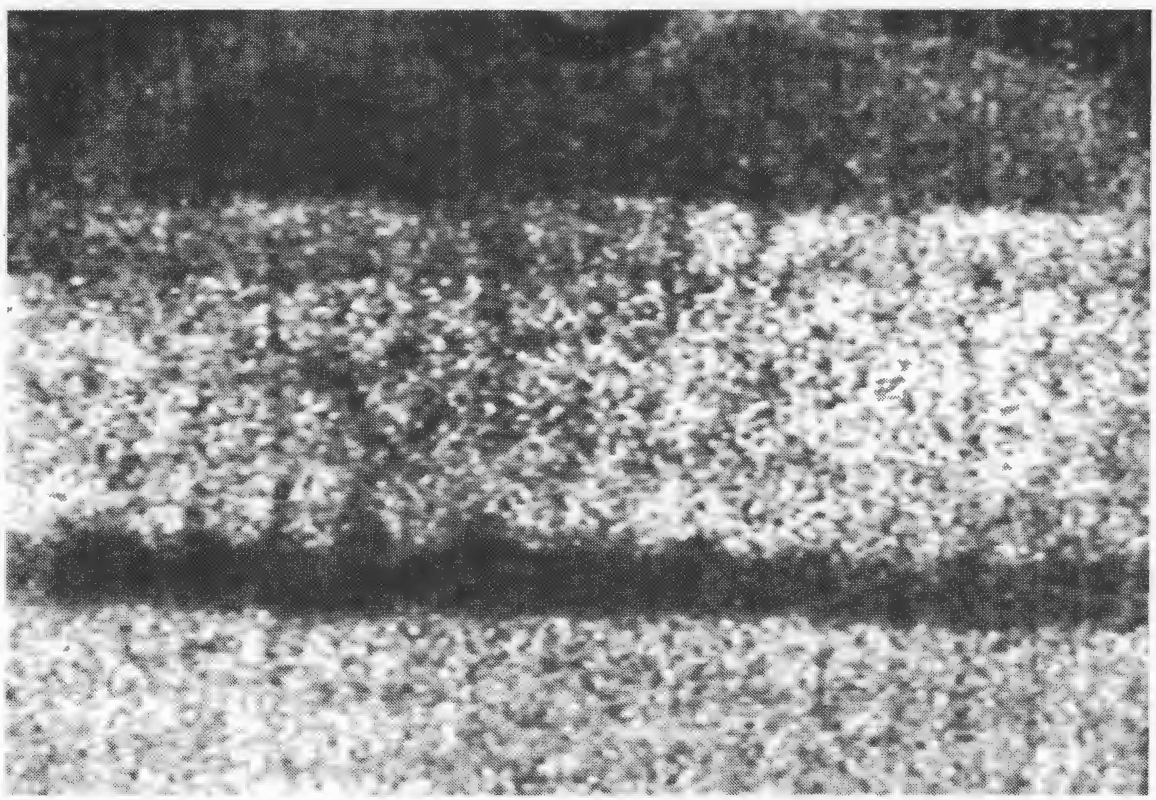
Figure 8. Shearogram of Center of Waffle Doubler.

REFERENCE

1. Bobo, S. N., "Shearographic Inspection of a Boeing 737," Federal Aviation Administration Technical Center, Report No. DOT/FAA/CT-TN92/19, July 1992.

APPENDIX A - SPECIFICATIONS OF SHEAROGRAPHIC INSTRUMENTATION

Specifications for the equipment provided by Laser Technology, Inc., are as follows.

Model	LTI 9200	LTI 980D
Tripod-Mounted Fixed-Focus		
Laser	Argon	IonDiode
Laser Output Power	200mW	80mW
Effective Output Power	80mW	80mW
Size (inches LxWxH)		
Optical Head	12x4x5	16x16x18
Electronics	22x22x24	22x22x24
Power		
Laser	110V @ 20A	110V @ 10A
Electronics	110V @ 10A	110V @ 10A
Cable Length (ft)	33	33
Field of View	25°x22°	14x11 in.

APPENDIX B - SHEAROGRAPHIC INSPECTION PROCEDURE

This document describes an inspection for disbonding of unriveted stringers on fuselage skins between flight compartment bulkhead and passenger door/emergency exit areas of DHC-7 aircraft.

PREPARATION:

In cooperation with the maintenance staff of the aircraft operator, the exterior surface of fuselage skins (between the flight compartment bulkhead and passenger door/emergency door) is visually inspected at the same time for disbonding along stringer lines and for loosening or working rivets at specified skin joints.

The inspection is carried out in three stages at separate times.

Remove any optional parts (such as S.O.O. 7161 ice guards) and clean off all anti-corrosion compounds beneath.

REQUIREMENT:

1. Inspect fuselage belly skins between X248.00 and X535.25 below stringers No.20 for disbonding along unriveted stringers. Also, inspect rivets at specified skin joints for looseness and working. Use procedures detailed in ACCOMPLISHMENT INSTRUCTIONS (Inspection Part A).

2. Inspect fuselage left and right hand sidewall skins between X248.00 and X596.75 above stringers No.20 and beneath stringers No.10 for disbonding along unriveted stringers. Use procedure specified in ACCOMPLISHMENT INSTRUCTIONS (Inspection Part B).

3. Inspect fuselage roof skins between X248.00 and X630.00 above stringers No.10 for disbonding along unriveted stringers. Use procedure specified in ACCOMPLISHMENT INSTRUCTIONS (Inspection Part C).

4. Report results of each inspection on each aircraft (whether or not loosening of rivets or disbonding is discovered).

If any looseness of rivets in the specified skin joints is detected, report exact details immediately.

LABOR HOURS:

Approximately eight labor hours will be required to carry out inspections Part A, B, and C.

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SPECIAL TOOLS:

Laser Shearography inspection unit, Model ES 9400 or equivalent.

ACCOMPLISHMENT INSTRUCTIONS:

Set jacks under appropriate hard points and remove sufficient load from tires to ensure LACK OF movement of the aircraft during inspection.

Attach blower to cabin air intake of aircraft in such a manner as to permit repeated pressurizations of the fuselage to a pressure no greater than 0.5 PSI. Time to reach 0.5 PSI should be 30 seconds to one minute.

Inspection Part A:

A1. Set up shearography equipment to focus on sections of belly of aircraft between X248.00 (flight compartment bulkhead) and X535.25 (ahead of passenger door and emergency door) beneath stringers No. 20. (See attached figures B1-B15 taken from Boeing Canada DeHavilland Division Service Bulletin DHC-7 (DASH 7) No. 7-53-33)

A2. Inspect as follows:
Focus shearography successively on sections of the belly of the aircraft between the areas noted in A1 above. At each site pressurize aircraft to 0.5 PSI while making a double exposure shearogram. Upon completion of each area, proceed to the next adjacent area and make successive shearograms, leaving about 10% overlap.

A3. Visually inspect for loose and working rivets in skin circumferential joints below stringers No. 20 at X535.25 and at X576.25. Pay particular attention to forward line of rivets.

A4. Inspect for loose and working rivets in skin circumferential joint at X630.00 above and below passenger and emergency doors. Pay particular attention to forward line of rivets.

A5. Inspect for loose and working rivets in skin longitudinal joint along stringers No. 20 left and right hand from X424 to X484. Pay particular attention to forward line of rivets.

A6. On each figure, mark aircraft serial number, accumulated flights and flight hours, date of inspection, dimensions of each suspect area and brand name and model number of equipment used. If no disbonding or loosened rivets are detected, mark each figure accordingly.

Inspection Part B:

B1. Set up shearography equipment to focus on sections of skin on fuselage sidewalls, left and right hand between X248.00 and X596.75 above stringers No. 20 and below stringers No 10, excepting area under wing-fuselage fairing.

B2. Inspect as follows:
Focus shearography equipment successively on sections of skin on fuselage sidewalls, left and right hand between the areas noted in B1 above. At each site, pressurize aircraft to 0.5 PSI while making a double exposure shearogram. Upon completion of each area, proceed to the next adjacent area and make successive shearograms, leaving about 10% overlap. (Cargo door, if fitted, and all emergency exit hatches need not be inspected).

B3. Report findings on figures B6 through B11 annotated as outlined under A6 above.

Inspection Part C:

C1. Set up shearography equipment to focus on fuselage roof between X248.00 and X630.00, excepting area under wing-fuselage fairing and dorsal fairing.

C2. Inspect as follows:
Focus shearography successively on fuselage roof between the areas noted in C1 above. At each site, pressurize aircraft to 0.5 PSI while making a double exposure shearogram. Upon completion of each area, proceed to the next adjacent area and make successive shearograms leaving about 10% overlap.

C3. Report findings on figures 12 through 15 annotated as outlined in A6 above.

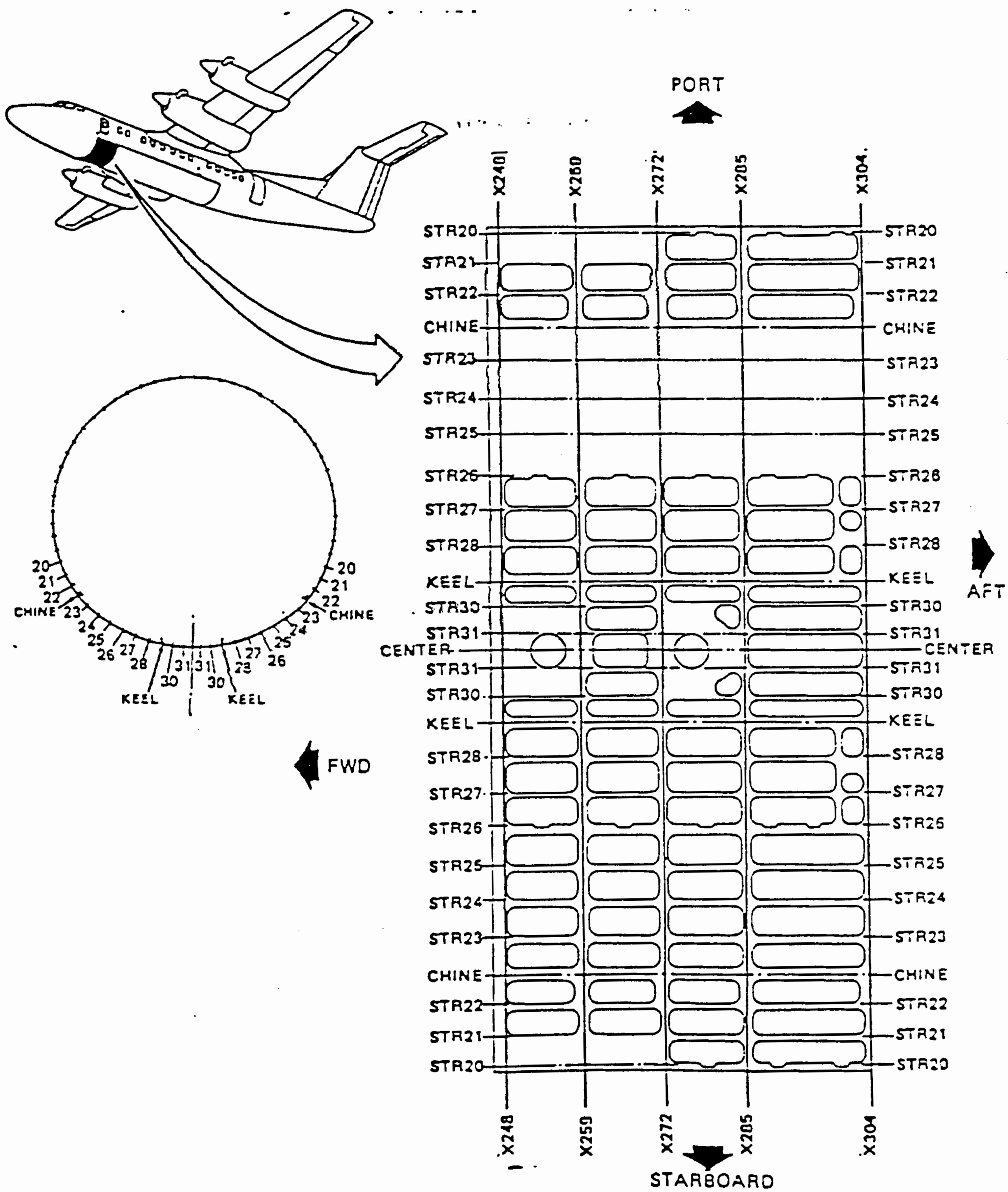


FIGURE B1. BELLY SKINS/WAFFLES/STRINGERS - X248 TO X304 (VIEW LOOKING UP THROUGH SKINS FROM BENEATH AIRCRAFT).

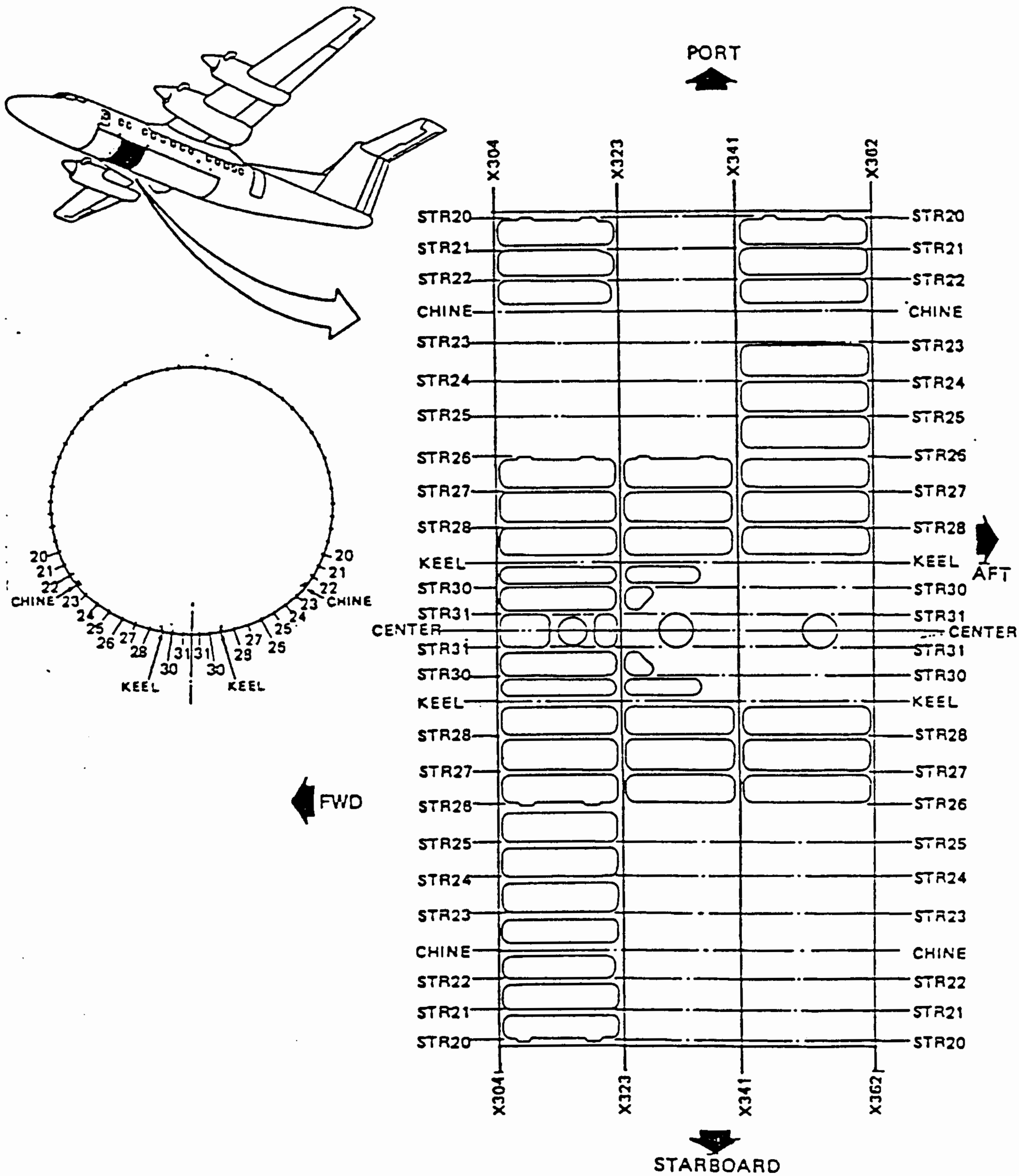


FIGURE B2. BELLY SKINS/WAFFLES/STRINGERS - X304 TO X362 (VIEW LOOKING UP THROUGH SKINS FROM BENEATH AIRCRAFT).

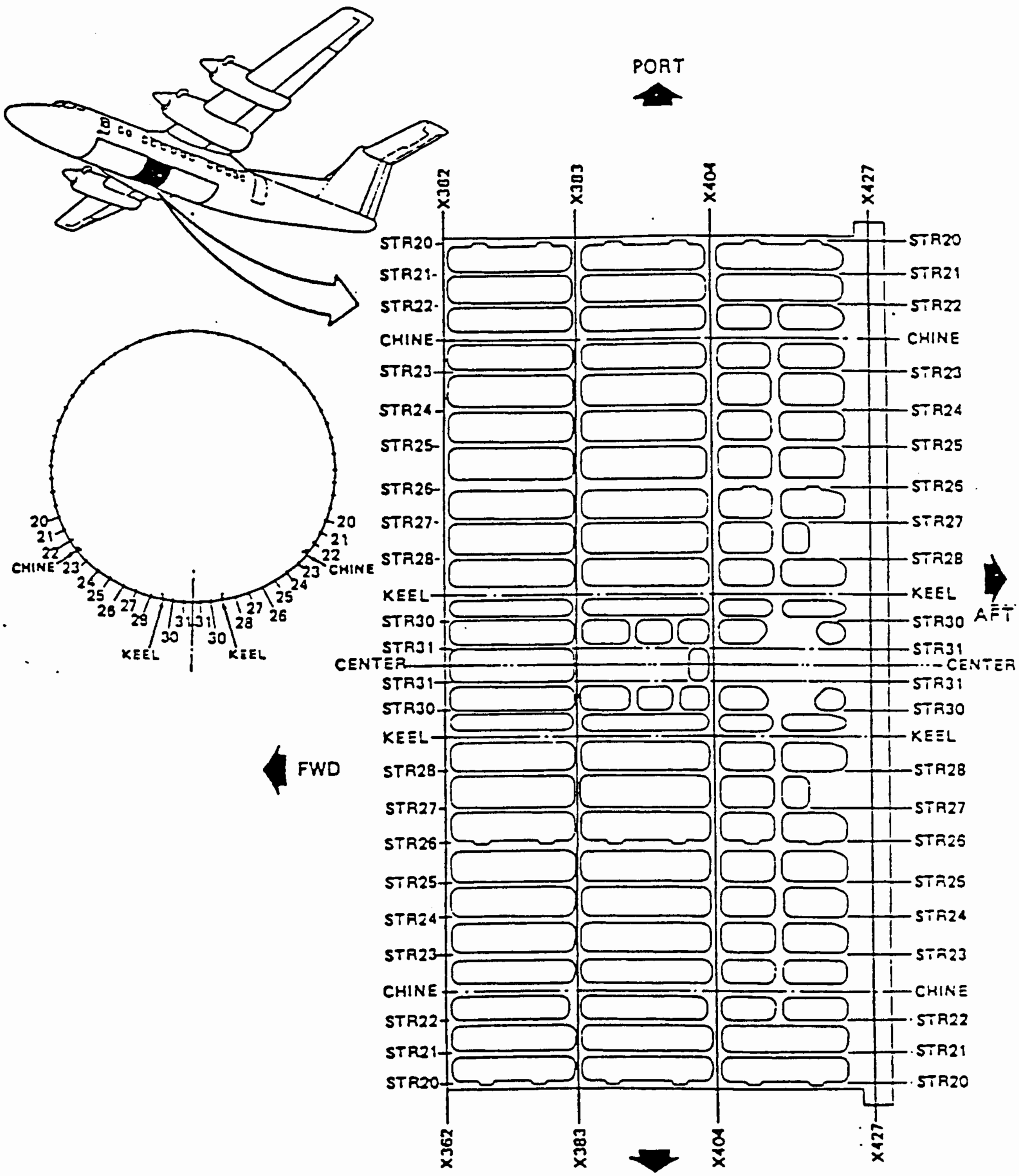


FIGURE B3. BELLY SKINS/WAFFLES/STRINGERS - X362 TO X427 (VIEW LOOKING UP THROUGH OUTER SKINS FROM BENEATH AIRCRAFT).

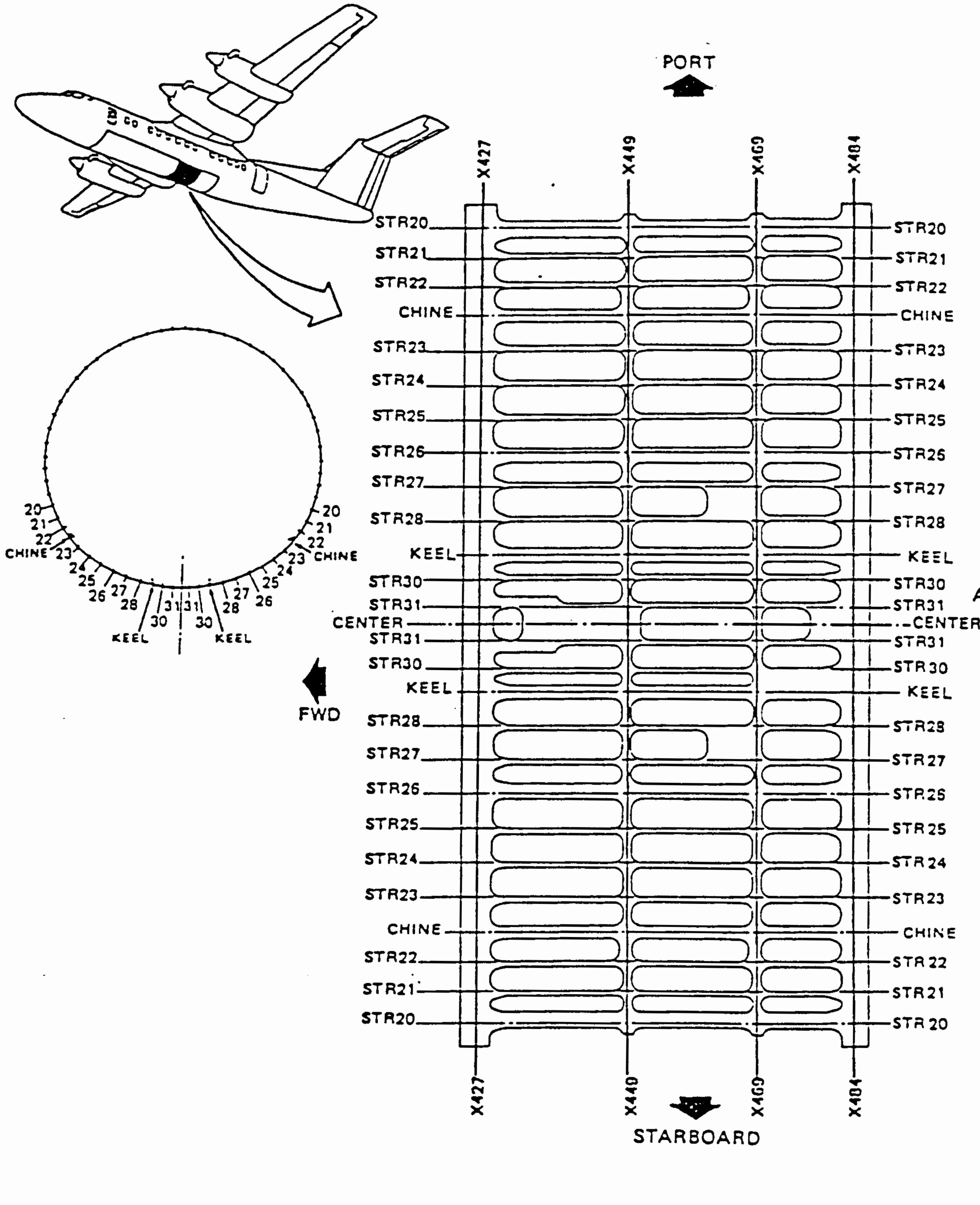


FIGURE B4. BELLY SKINS/WAFFLES/STRINGERS - X427 TO X484 (VIEW LOOKING UP THROUGH OUTER SKINS FROM BENEATH AIRCRAFT).

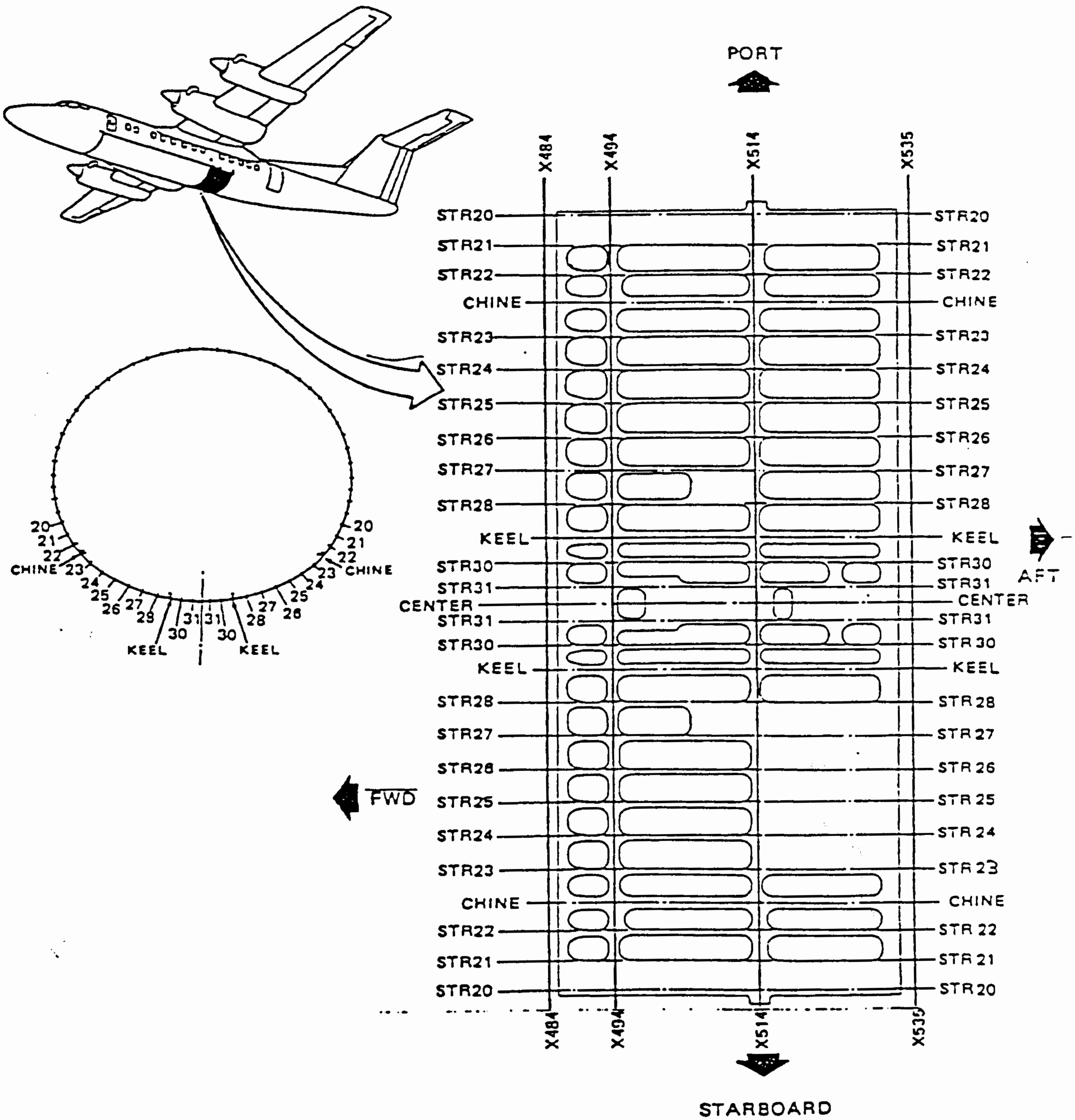


FIGURE B5. BELLY SKINS/WAFFLES/STRINGERS - X484 TO X535 (VIEW LOOKING UP THROUGH OUTER SKINS FROM BENEATH AIRCRAFT).

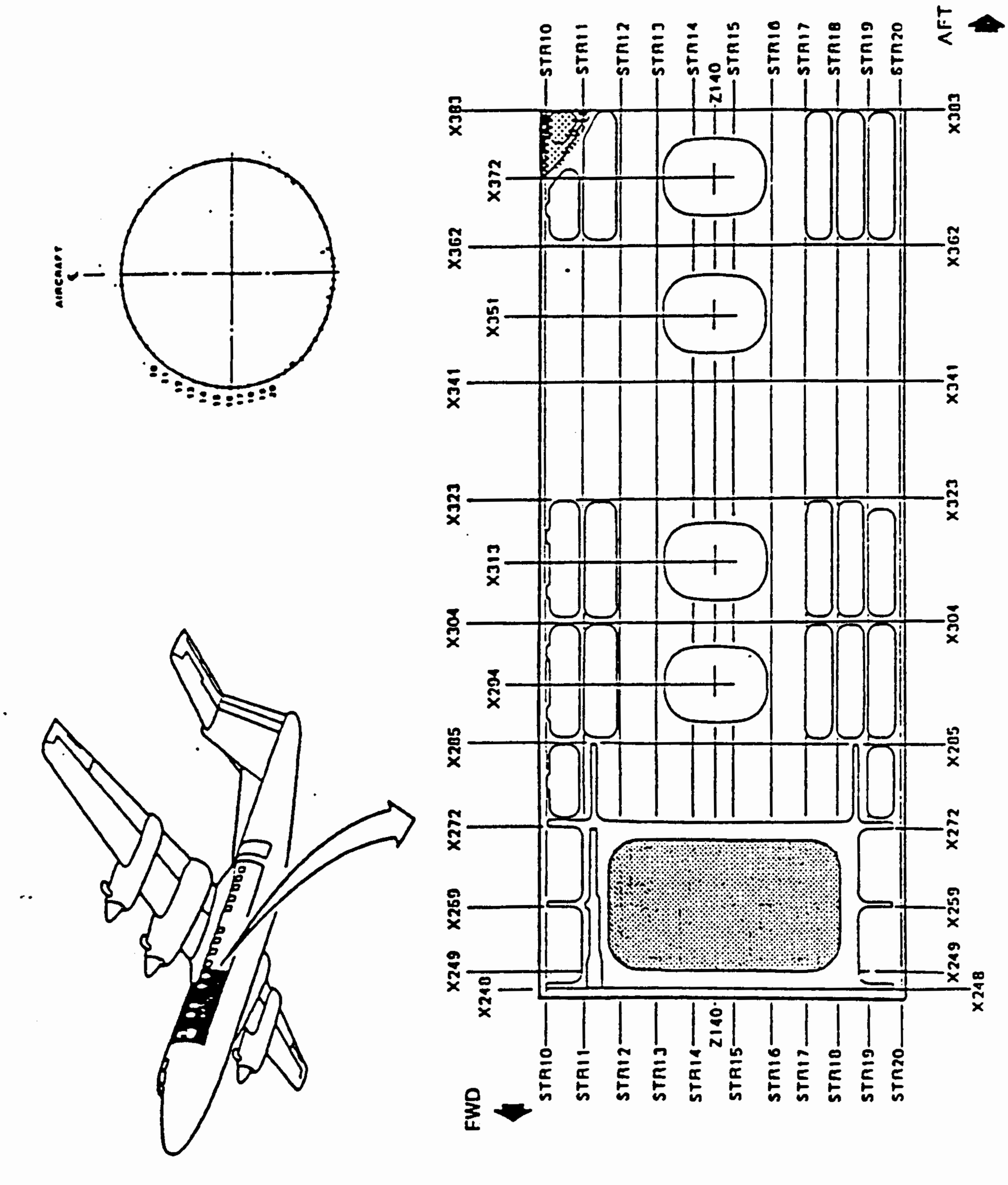


FIGURE B6. SIDEWALL SKINS/WAFFLES/STRINGERS - X248 TO X383 (VIEW FROM EXTERIOR OF AIRCRAFT LEFT HAND SIDE. SHADED AREAS-EMERGENCY EXIT HATCH AND UNDER FAIRING-DO NOT REQUIRE INSPECTION).

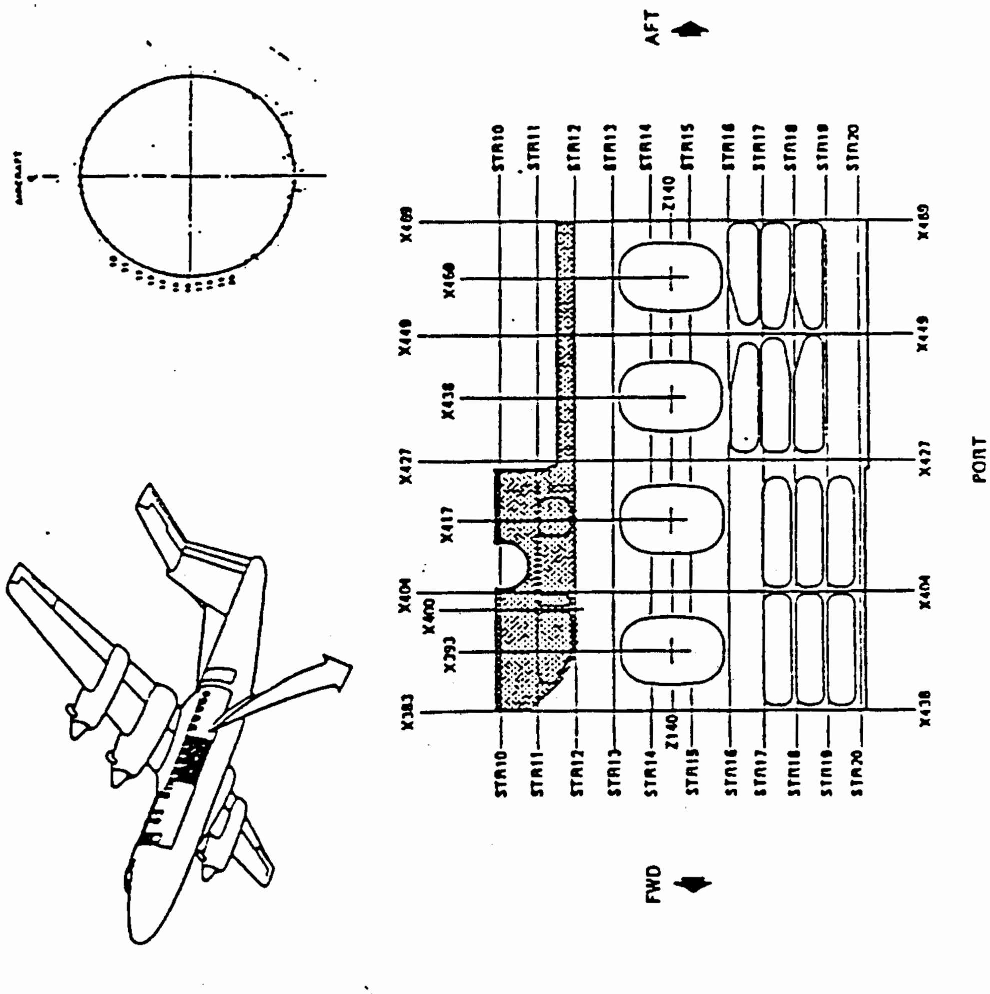


FIGURE B7. SIDEWALL SKINS/WAFFLES/STRINGERS - X383 TO X469 (VIEW FROM EXTERIOR OF AIRCRAFT LEFT HAND SIDE. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

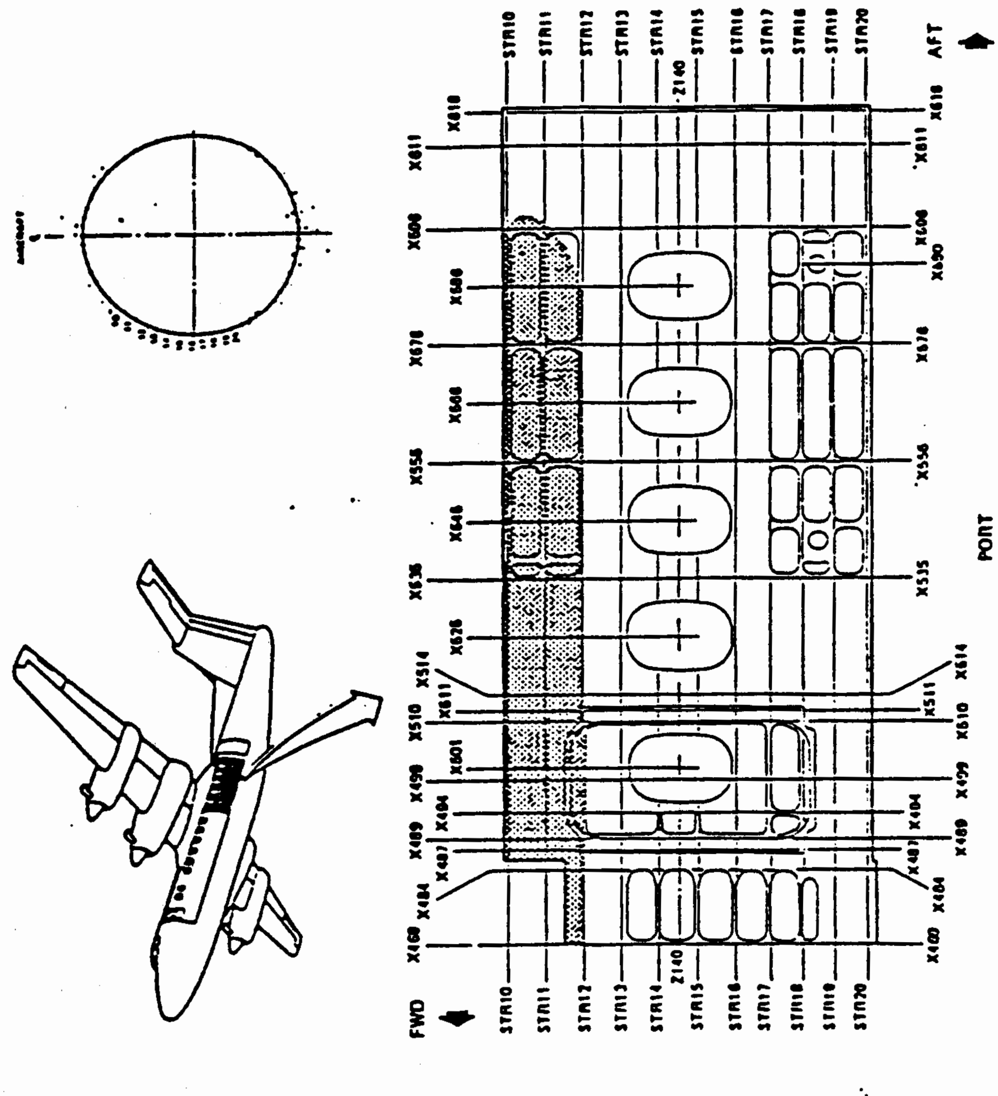


FIGURE B8. SIDEWALL SKINS/WAFFLES/STRINGERS - X469 TO X616 (VIEW FROM EXTERIOR OF AIRCRAFT LEFT HAND SIDE. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

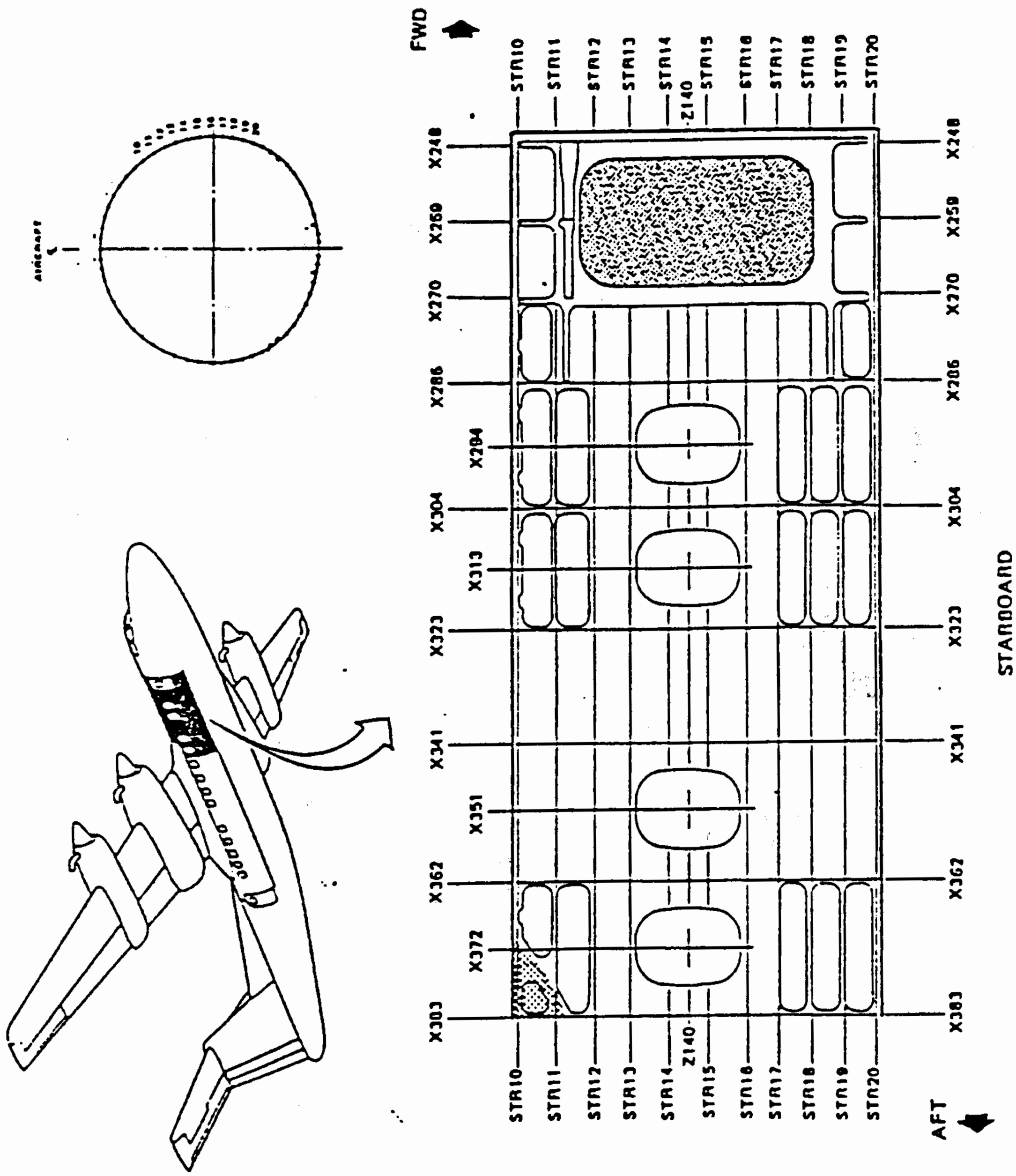


FIGURE B9. SIDEWALL SKINS/WAFFLES/STRINGERS - X248 TO X383 (VIEW FROM EXTERIOR OF AIRCRAFT RIGHT HAND SIDE SHADED AREAS - EMERGENCY ESCAPE HATCH UNDER FAIRING - DO NOT REQUIRE INSPECTION).

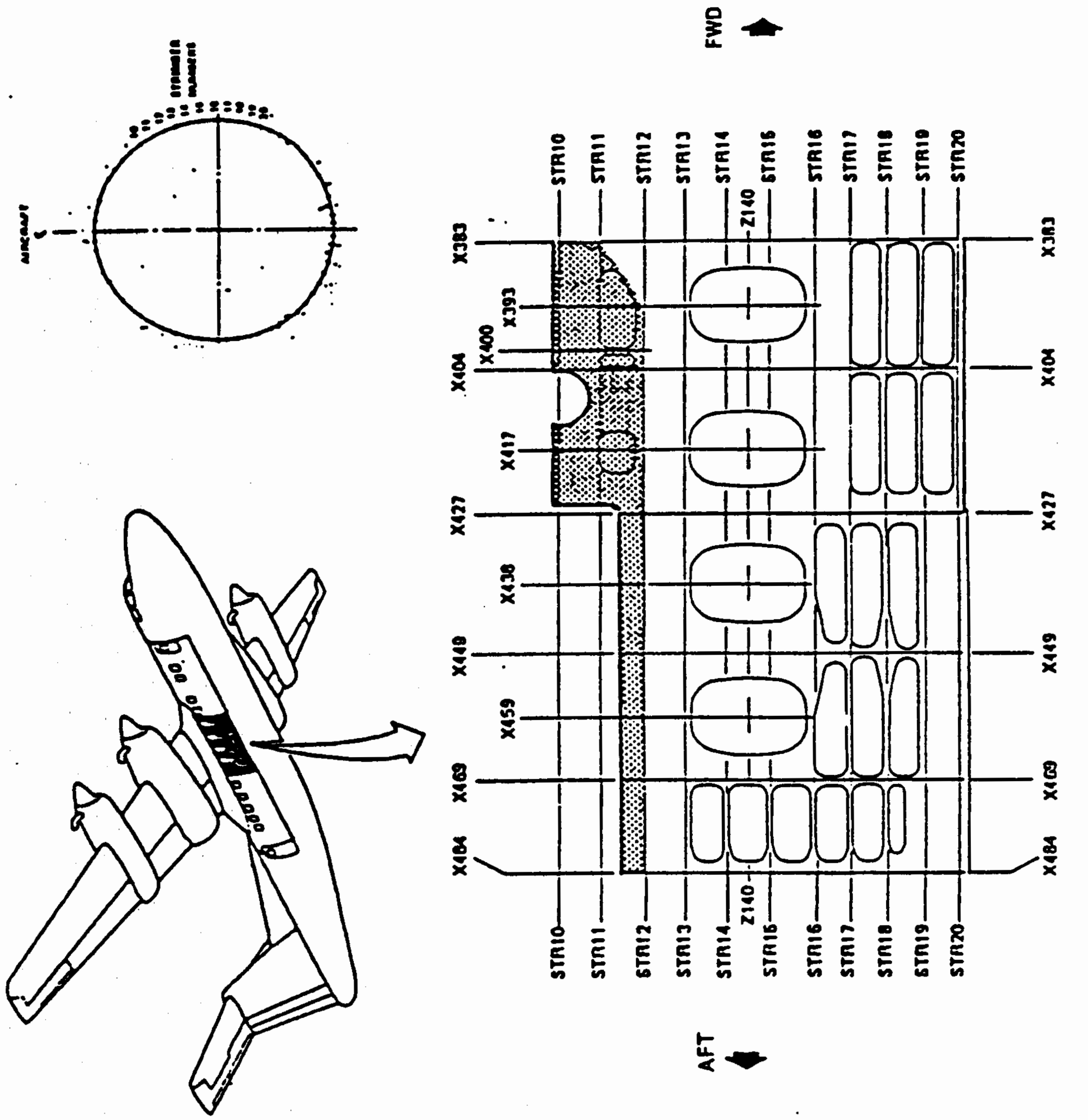


FIGURE B10. SIDEWALL SKINS/WAFFLES/STRINGERS - X383 TO X484 (VIEW FROM EXTERIOR OF AIRCRAFT RIGHT HAND SIDE. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

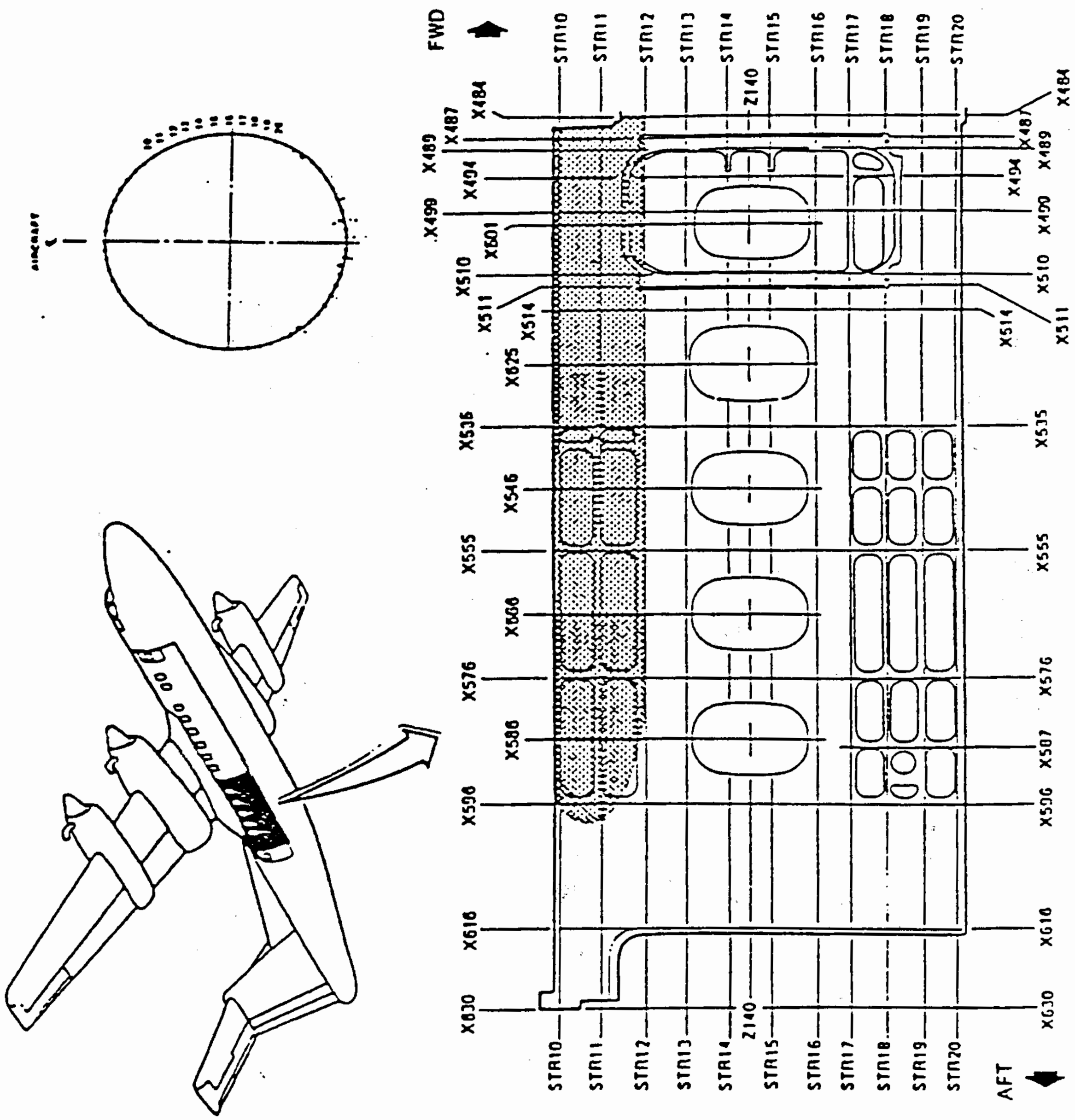


FIGURE B11. SIDEWALL SKINS/WAFFLES/STRINGERS - X484 TO 630 (VIEW FROM EXTERIOR OF AIRCRAFT RIGHT HAND SIDE. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

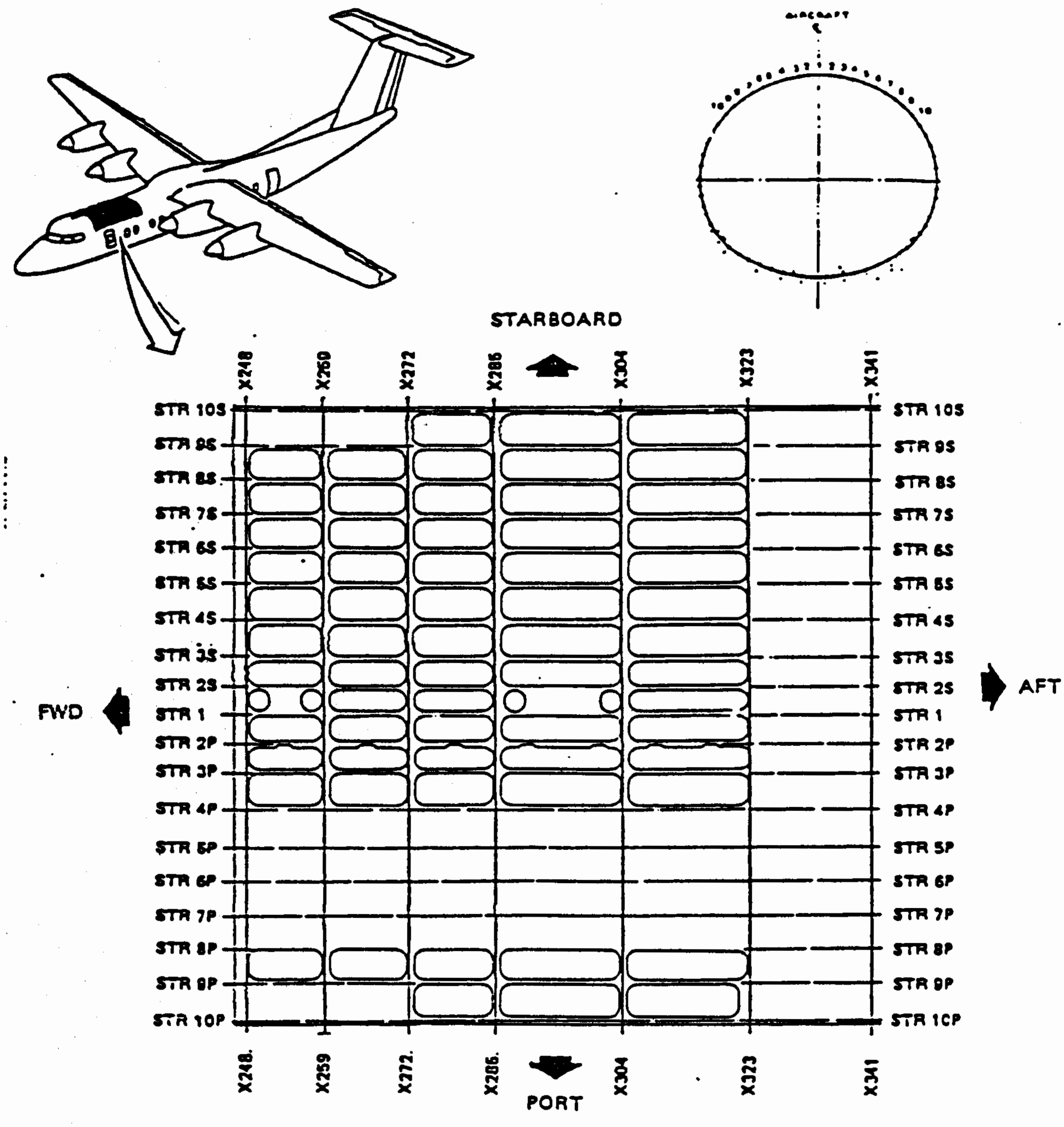


FIGURE B12. ROOFS SKINS/WAFFLES/STRINGERS - X248 TO X341 (VIEW FROM EXTERIOR OF AIRCRAFT).

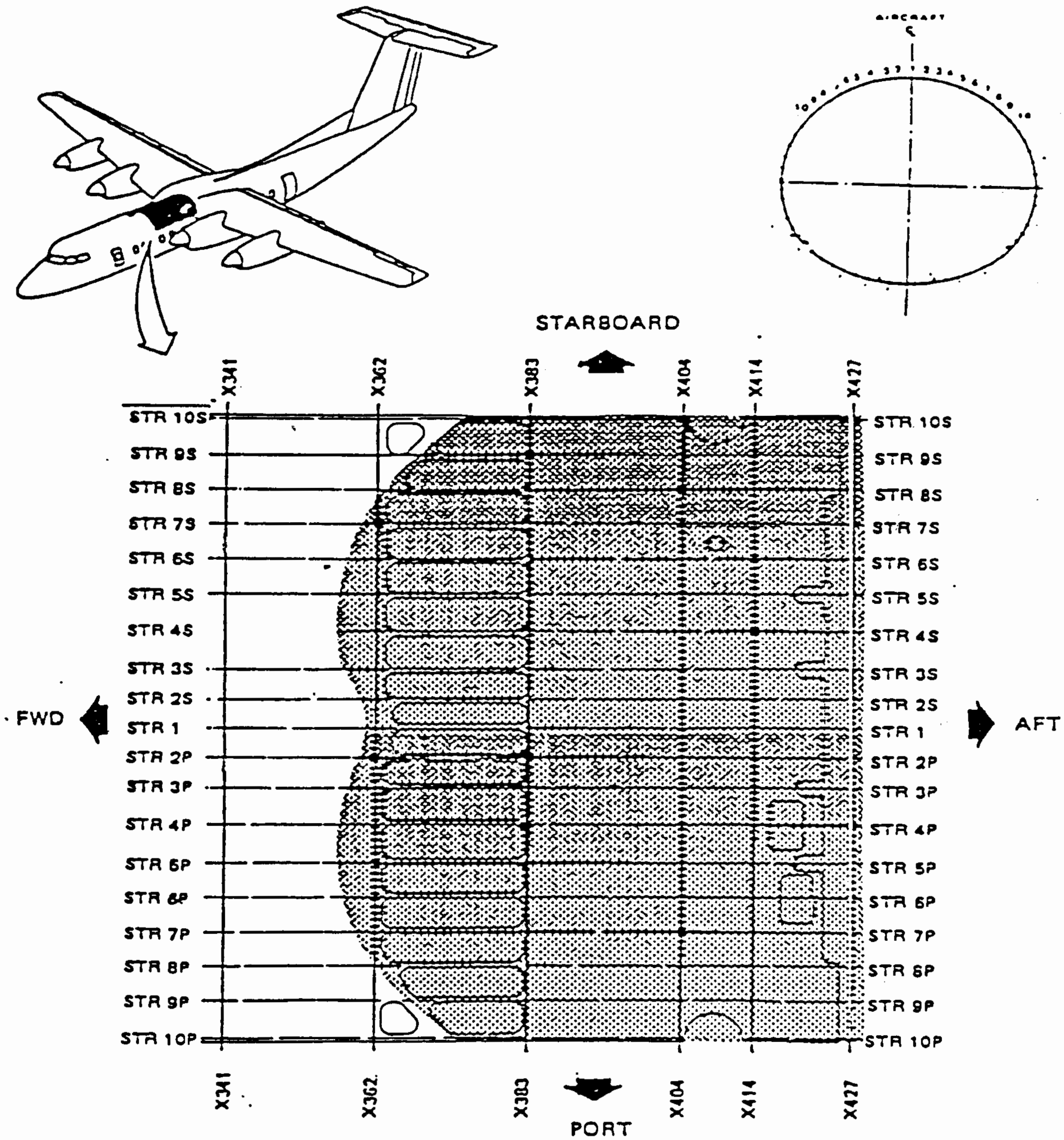
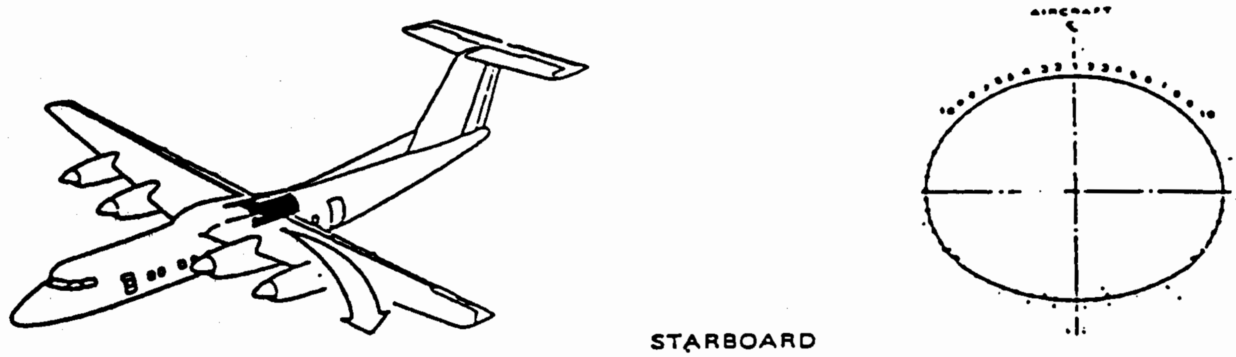


FIGURE B13. ROOFS SKINS/WAFFLES/STRINGERS - X341 TO X427 (VIEW FROM EXTERIOR OF AIRCRAFT. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).



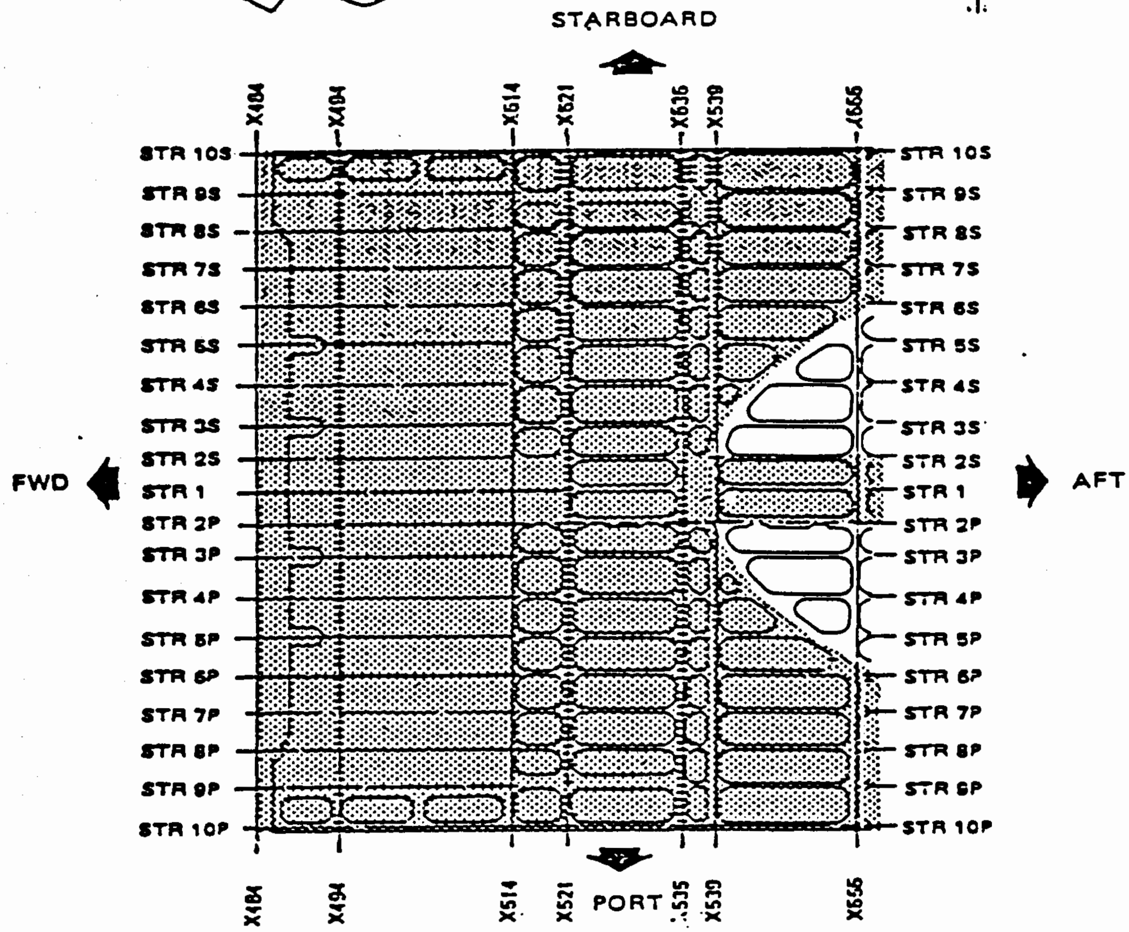


FIGURE B14. ROOFS SKINS/WAFFLES/STRINGERS - X484 TO X555 (VIEW FROM EXTERIOR OF AIRCRAFT. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

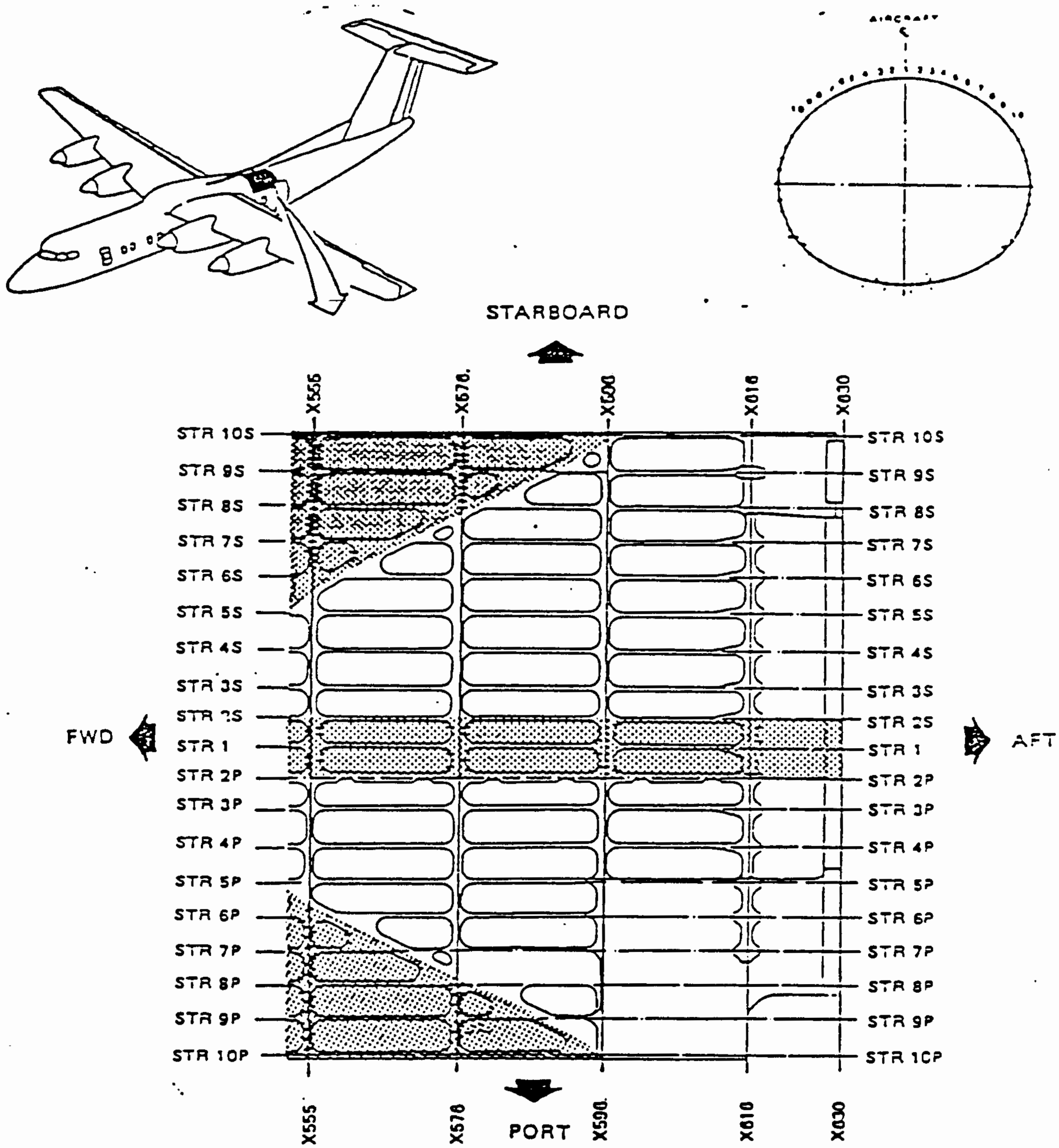


FIGURE B15. ROOFS SKINS/WAFFLES/STRINGERS - X555 TO X630 (VIEW FROM EXTERIOR OF AIRCRAFT. SHADED AREA UNDER FAIRING DOES NOT REQUIRE INSPECTION).

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