# THE EXAMINATION OF AIRCRAFT TIMBER BY X-RAYS

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About the middle of 1918 the Aeronautical Inspection Department decided to ascertain what measure of practical assistance the X-rays would afford to its timber-inspecting staff in their efforts to ensure that high standard of quality and workmanship which experience has shown to be so essential. The idea was put to the test, using the equipment of the Cancer Hospital (by kind permission of the Governors). The results were very encouraging, but owing to the severe pressure of other matters progress was somewhat delayed, and at the time of the Armistice, the method had not reached the stage of commercial application. But sufficient examples had been obtained to demonstrate the value of X-rays in this connection, and the only questions remaining were those arising out of equipment—portability, convenience, and the like.

We would like here to acknowledge our great indebtedness to Lieut. Hudson-Davies, who throughout has shown the keenest practical interest. Mr. G. F. Westlake is responsible for most of the radiographic work.

It was realised from the start that for the method to be worth while, it must permit the rapid visual examination of the part under inspection. This naturally implies fluorescent-screen examination, photography being reserved purely for permanently recording such cases which the screen shows to be of interest.

All woods are particularly transparent to X-rays, and soft X-ray tubes were necessary, the alternative spark gap being usually from 1 to 2 inches between point electrodes. It may be remembered that the efficiency of both the output of an X-ray bulb and the excitation of a fluorescent screen are much less with soft than with hard rays, and it is therefore expedient to use rays as hard as are feasible for the work in hand. A high tension transformer and Coolidge tube were mostly employed, the latter being adjusted to give an abundance of rays of long wave length, some 15 milliamperes being passed through.

As already remarked, in the construction of all parts of aircraft, the best workmanship and material of the highest quality are essential owing to the low factor of safety. X-rays may thus be resorted to at two periods :—

(1) While the material is in the rough unfinished condition, and

(2) When the part is assembled and ready for employment.

It will be convenient to consider these stages separately.

## I. *Examination of Raw Material.*

The chief defects that had to be looked for in aeronautical timber during the war were spiral grain (in spruce and spruce substitutes), large hidden knots, large resin pockets, compression shakes, incipient decay (including dote), grub-holes, very light wood, etc.

It was realised that the method of X-ray diagnosis could only be helpful in revealing differences of density; and, as was anticipated, no difficulty whatever was experienced in detecting hidden knots and resin pockets, grub-holes, and the like. "Localising" depth as well as position was attained by radiographing both a front and a side view.

Localising by stereoscopy can also be employed, and actual measurements of depth obtained.

If the specimens are not too thick, it is possible, though only with difficulty, to detect compression-shakes, incipient rot and spiral grain. The chief feature, however, that the X-rays bring out is the difference between the light spring and the denser summer growths, *i.e.*, the annual rings of the tree. From a practical standpoint this is only useful in detecting the presence of localised hard grain—an objectionable feature for aircraft purposes. Figs. 1 to 6 show radiographs of different aeroplane woods, all of high quality. The chief feature in those photographs taken tangentially to the annual rings is the "grain" produced by the annual rings. The true grain or fibre is not shown in most of the photographs.

It might be remarked that the method of inspection by X-rays is still in its infancy and that with increasing experience in technique and improvements in plates and photographic methods better results will follow.

*Figure* 1. *Canadian White Pine,* radiographed tangentially to annual rings.

*Figure* 2. *West Virginian Spruce,* radiographed tangentially to annual rings. The ribbed effect is marked. The dark band running down the centre is due to the closer growth over this region which was also deeper in colour.

*Figure* 3. *Oregon Pine.* Cross-grained material radiographed tangentially to annual rings. The dark bands coincide with the redder colour of the regions in question.

*Figure* 4. *Silver Spruce,* radiographed tangentially to annual rings. Note the rope-like effect.

*Figure* 5. *Silver Spruce.* A highly figured specimen radiographed tangentially to the annual rings. The curious criss-cross effect is doubtless due to the presence of the "figure," which is caused by elongated depressions in the annual rings repeated from year to year.

*Figure* 6. *Silver Spruce showing glued joint,* radiographed "radially" to annual rings. The slant of the fibre is faintly shown ascending towards the left, but interest chiefly attaches to the clearness with which a well-made glued joint is shown. The X-rays will infallibly detect either excess or deficiency of glue between glued surfaces.

To sum up, it cannot be claimed for the X-rays when used in examining timber as material that they will tell an experienced and observant timber expert any more than he can deduce from an "outside" visual inspection of either the rough timber or the semi-finished part. But such experts are not found everywhere, and it would appear that the X-rays would supplement very usefully the semi-skilled labour on which we had partly to rely in inspectional work during the war.

## II. *Examination of Timber Details.*

It is in connection with finished and assembled parts that the X-rays show their greatest usefulness. This is not so much the case with parts made of solid wood as with those constructed on the laminated or "box" principle. This method of construction—which was introduced at a time when the country's supplies of high-grade aeronautical timber were seriously endangered—enables much smaller timber to be used but adds very greatly to the difficulties of inspection. Owing to the type of construction it is possible for many defects to be concealed from view, a fact of which a careless or unscrupulous workman is not unnaturally aware. In several cases such concealed faulty workmanship or defective material has been the cause of serious accidents. The vigilance of the inspectors during the process of construction prevented very many more accidents. It must, of course, be realised under what high pressure the various aircraft builders were working during the war, and the fact speaks for itself that in spite of grave difficulties of both labour and material, British aeroplanes were superior both in quality and numbers to those of any other nation. But there is the tendency which is known to exist in some natures to try to conceal a mistake due to a slip, especially when, from a lack of knowledge of design, the importance of the mistake might be underrated. During the war the various aircraft factories, with this in mind, displayed large notices reminding the staff that "A concealed mistake may cost a brave man his life."

It goes without saying that certain members of an aeroplane structure are more important than others, and that in minor parts departure from highest quality material or workmanship may not be attended with serious consequences. But it is imperative in the case of vital parts that nothing should be tolerated which will imperil or reduce the factor of safety of the machine.

Of these important items, the most vital are:—

(a) Main-plane wing spars—which pass from end to end of each wing.

(b) Compression struts—which separate the spars in each wing.

(c) Interplane struts—which separate the upper and lower planes.

(d) Longerons, cross struts and engine bearers—which make up the fuselage.

In most of these instances the composite, laminated, or hollow "box" method of construction is permissible. In some examples the strut or spar is completely covered with fabric, veneer, or plywood; and ordinary visual inspection of the final part is just as ineffective as with hollow spars or struts of the "box" type. An inspector cannot "stand over" the job all the time, and in many cases has to be content with examination of the part in question when it is put up for final approval. But he now receives a powerful ally in the X-rays, which clearly reveal the quality of workmanship and material of the internal structure of the aeroplane part.

The following examples are selected as illustrating some of the directions in which the method has been developed :—

*Figure* 7 shows the front and side view of the end of a hollow box strut. The internal strengthening block is seen to be badly fitted and each of the screws has split the wood, making altogether insecure and poor work.

*Figure* 8 is the front and side view of a hollow main-wing spar. In this, poor workmanship is shown in the cutting to shape of the internal block. The block is also split across the centre, facilitating the breaking of the spar under shear stresses.

*Figure* 9. This shows the side view of a hollow aileron spar. The spar consists of two halves fitted together by glued joints down centre. It is important that both sides of the outer skin should be of the same thickness; but in reducing the glued-up spar to correct finished dimensions, workmen are apt to plane away more wood from one side than from the other, occasionally reducing the strength to a critical degree. The use of X-rays affords an immediate indication if this is the case. Sometimes the internal block is misplaced or omitted from one of the halves and its absence cannot be determined by external examination. In the present case, the block is correctly placed.

*Figure* 10. Front and side view of portion of laminated spar consisting of three layers of wood glued together. The outside surfaces are perfect all round, but the X-rays disclosed a large knot and grub-holes in the middle layer, which would have had the effect of dangerously weakening the spar.

*Figure* 11 is a portion of a hollow tail boom which was presumed to be fitted with a solid block. The radiograph shows the shoddy arrangement actually fitted.

*Figure* 12. A skid was cut off too short to fit properly into its socket, and, to make up the necessary length, a piece of packing was introduced into the space below. (Shown dark at " B "). [The skid socket was of aluminium about 1/8th inch thick. The alternative spark gap was 8 inches between points, and the current through the tube 10 milliamperes.] In a wing skid like the example shown, this would not be a vital matter, but the same practice has been found in connection with the ends of interplane struts, where serious consequences might result in the event of their escaping detection.

*Figure* 13. This is another example of defective work at the base of a strut—in this case an internal compression strut in a wing. The strut was not made to enter the steel socket properly, and left an empty space at " X." Externally nothing could be seen that would suggest defective work, but the effect of this bad fitting would be that under vibration the strut would gradually work its way into the bottom of the socket, the straining wires " A " would become slack, thus increasing the chances of an accident in the air. The steel socket was 1/20th inch thick.

*Figure* 14. In the assembly of certain components in aeroplane construction, bolts which cross a member in various directions frequently occur in close proximity to each other. A mistake in the boring of the bolt-holes sometimes results in insufficient clearance between the bolts. This has occurred both in spars and in longerons. *Figure* 14 shows an X-ray projection of two such bolts in position. They presented a correct external appearance. The radiograph shows that something is wrong.

*Figure* 15 is an ordinary photograph of the same bolts taken out. It will be noted that the bolt on the left-hand side has been heavily grooved. In one case alone where this condition was detected further examination of the batch resulted in the rejection of dozens of completely finished main wing planes. Had this condition remained undetected, it would undoubtedly in some cases have resulted in loss of life.

Many other types of defects to be met with from time to time would also admit of clear detection by means of X-rays. For instance, the occasional misplacement of the cable controls that pass through the inside of the completed wings. Cases have been found where these follow a wrong path and have been threaded through wrong positions, or have been caught up while the fabric was being sewn to the ribs. Happily, most of these cases have been detected by trial of the sensitiveness of the control before flight.

In other minor cases, also, X-rays could be made to provide useful information. For example, in the use of knotty or split wood or bad distribution of cement in the centres of three-ply boards. Or again, in *Figure* 16, where a defective overlap together with a gap occur in the internal plies. This example occurred in multi-ply intended for use in engine bulkheads and engine bearers, and the defects in each case lie deep in the body of the plywood. They could not be seen by any external examination, and might have had disastrous effects.

Similarly, the case of a split longeron which had a shaving glued over a crack. After sandpapering, the defect was admirably concealed, but was remorselessly revealed by the X-rays.

Or finally the case of the rivets in the petrol tank, which proved to have heads on the outside only and none inside. *Figure* 17 is a radiograph of the end of a steel petrol tank showing soldered seam.

But enough has been said to demonstrate the utility of the X-rays as a powerful supplementary instrument for the aircraft inspector in his efforts to further the aim of the constructor to build machines as well nigh perfect as anything made by man can be. Mention should also be made of the value of the X-rays in investigating the causes of accidents. Very large radiographs can be taken on films or radioprint paper. Already direct prints 8 ft. × 4 ft. have been taken, and this could easily be extended to 20 ft. × 10 ft. if necessary. The cost would be relatively trifling, and in any event the safety of the pilots and observers demands that nothing shall be left undone which will add to their sense of security. The method may prove to be a valuable adjunct in encouraging in the general public a taste for travelling by air.

With reference to the commercial development of the method there would be no difficulty on the score of portability of apparatus. There

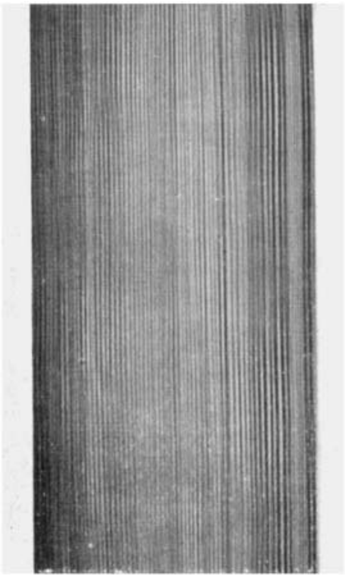

Fig. 1.
Canadian White Pine.

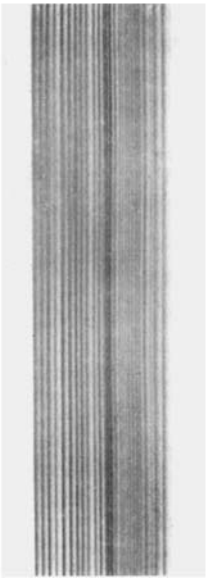

Fig. 2.
West Virginia Spruce

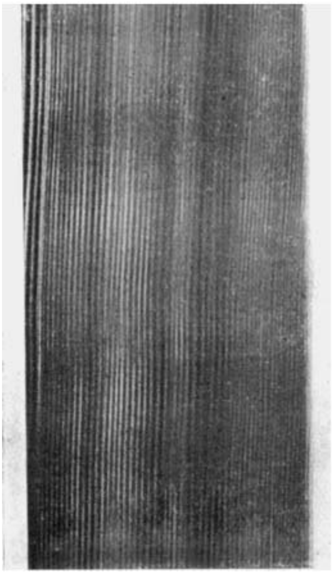

Fig. 3.
Oregon Pine.

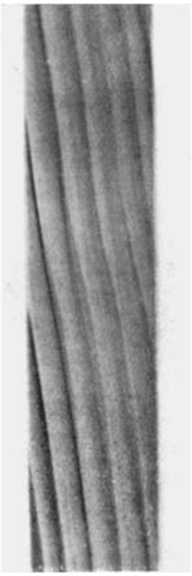

Fig. 4.
Silver Spruce.

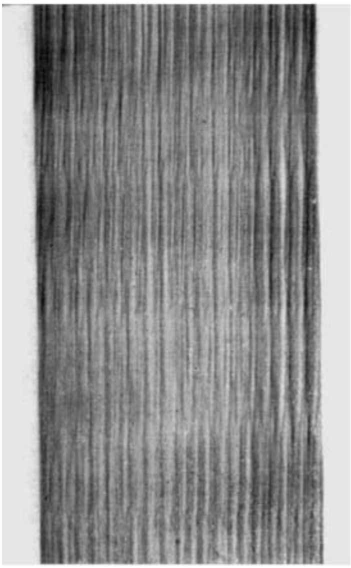

FIG. 5.
SILVER SPRUCE.

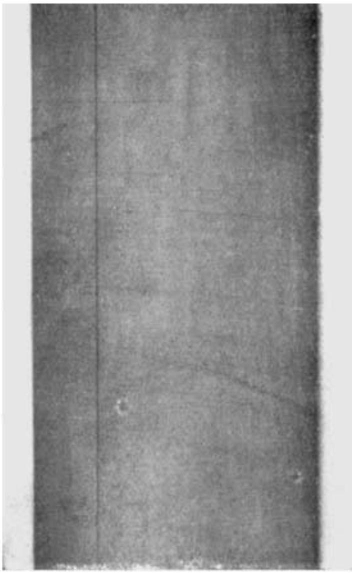

FIG. 6.
SILVER SPRUCE.

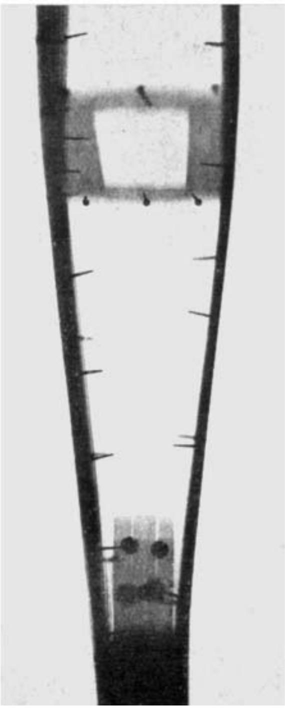

FIG. 7.
X-RAY PHOTOGRAPH SHOWING THE INTERIOR OF THE END OF A HOLLOW "BOX" AEROPLANE STRUT. THE INTERNAL STRENGTHENING BLOCK AT THE END IS SEEN TO BE BADLY FITTED AND EACH OF THE SCREWS HAS SPLIT THE BLOCK.

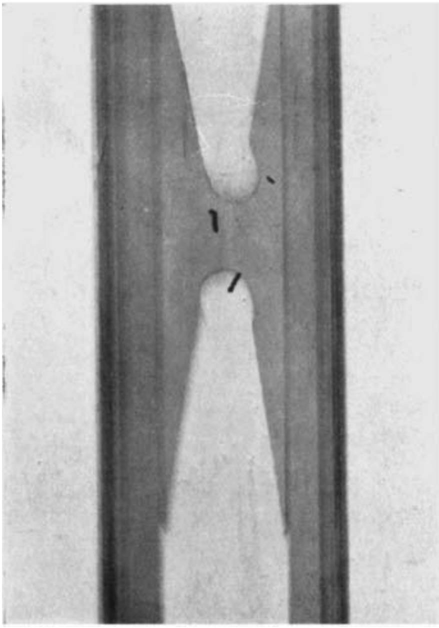

FIG. 8.

X-RAY PHOTOGRAPH OF HOLLOW MAIN-WING SPAR. POOR WORKMANSHIP IN INTERNAL STRENGTHENING BLOCK.

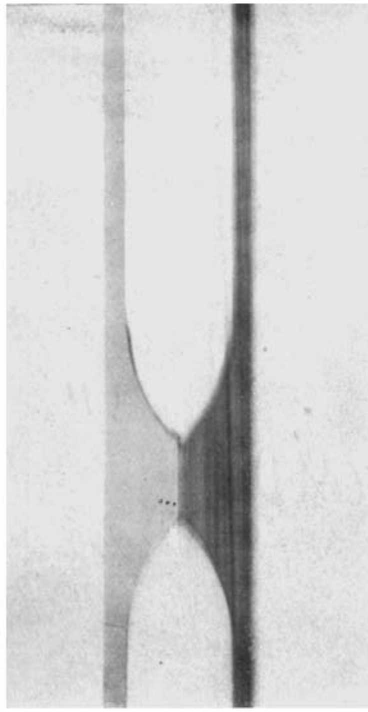

FIG. 9.

X-RAY PHOTOGRAPH SHOWING SIDE VIEW OF HOLLOW AILERON SPAR CONSISTING OF TWO HALVES GLUED TOGETHER AFTER SIDES HAVE BEEN SPINDLED OUT. THE TWO HALVES OF THE CENTRAL BLOCK SHOULD REGISTER ACCURATELY, AND THE SIDES SHOULD BE EQUALLY THICK.

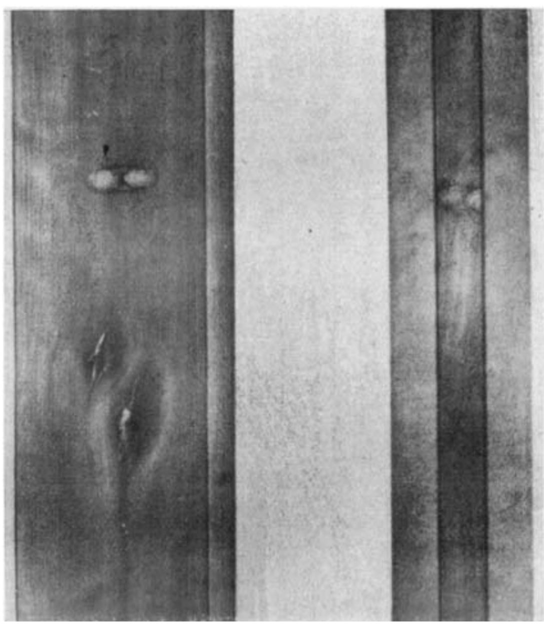

FIG. 10.

X-RAY PHOTOGRAPH SHOWING FRONT AND SIDE VIEWS OF A LAMINATED WOODEN SPAR OF AN AEROPLANE. THE SPAR IS MADE UP OF THREE LAMINAE GLUED TOGETHER. THE EXTERNAL APPEARANCE DID NOT INDICATE THAT THE MIDDLE LAYER CONTAINED TWO KNOTS AND A GRUB-HOLE AND SHOULD NOT HAVE BEEN USED.

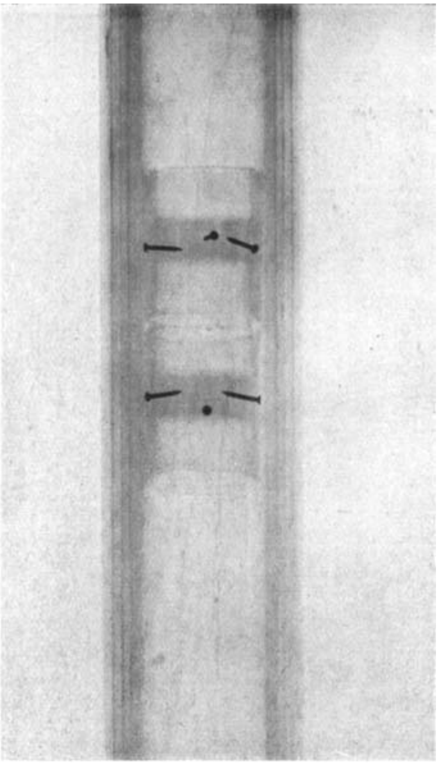

FIG. 11.
X-RAY PHOTOGRAPH SHOWING HOLLOW TAIL BOOM WHICH WAS PRESUMED TO BE FITTED WITH A SOLID INTERNAL BLOCK.

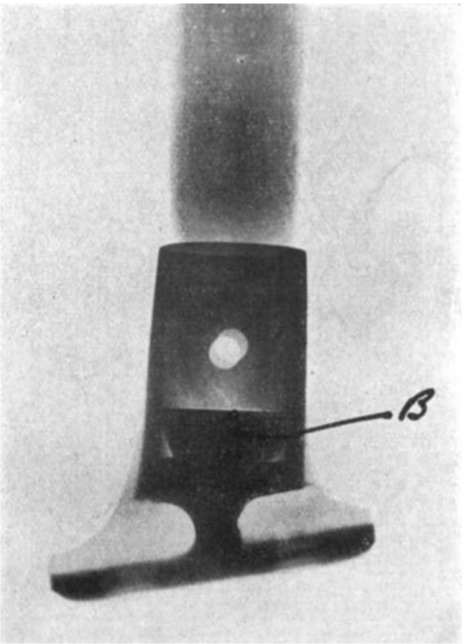


FIG. 12.
X-RAY PHOTOGRAPH OF AN AEROPLANE WING-SKID WHICH DID NOT BED PROPERLY INTO ITS ALUMINIUM SOCKET. THE WOOD SKID WAS CUT OFF TOO SHORT, AND A PACKING PIECE (B) WAS INTRODUCED INTO THE SPACE BELOW.

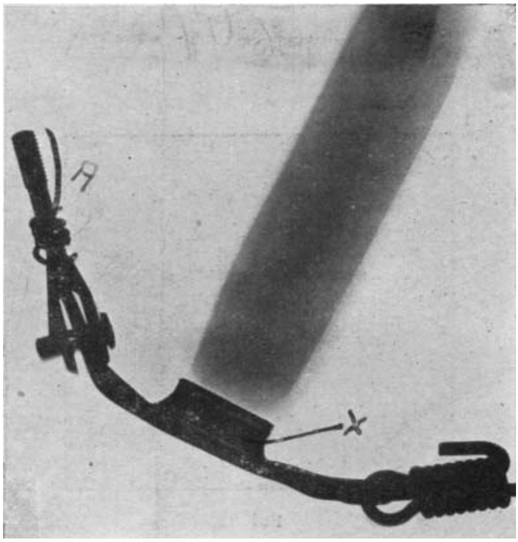


FIG. 13.
X-RAY PHOTOGRAPH OF AN INTERNAL COMPRESSION STRUT WHICH DID NOT PROPERLY BED INTO ITS STEEL SOCKET.

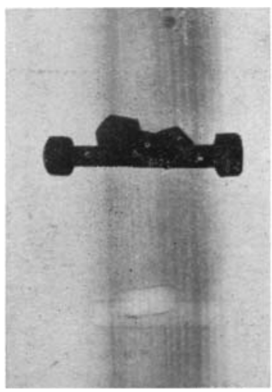

FIG. 14.
X-RAY PHOTOGRAPH SHOWING TWO BOLTS FOULING EACH OTHER IN CROSSING AN AEROPLANE SPAR

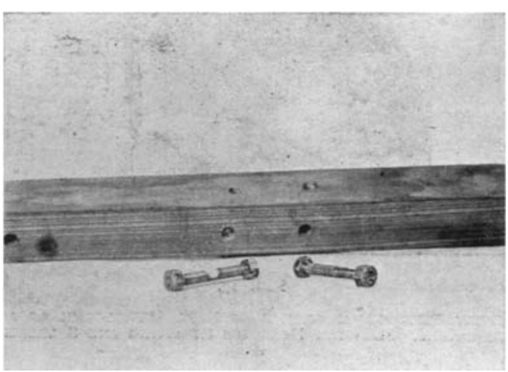

FIG. 15.
SHOWS SAME BOLTS WITHDRAWN.

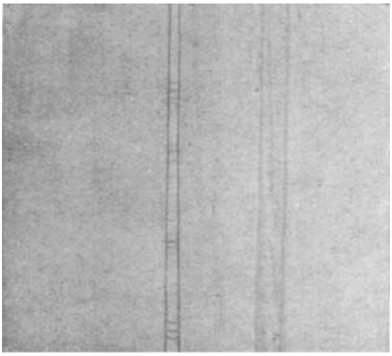

FIG. 16.

X-RAY PHOTOGRAPH SHOWING OVERLAP AND GAP IN INNER LAYERS OF MULTI-PLYWOOD.

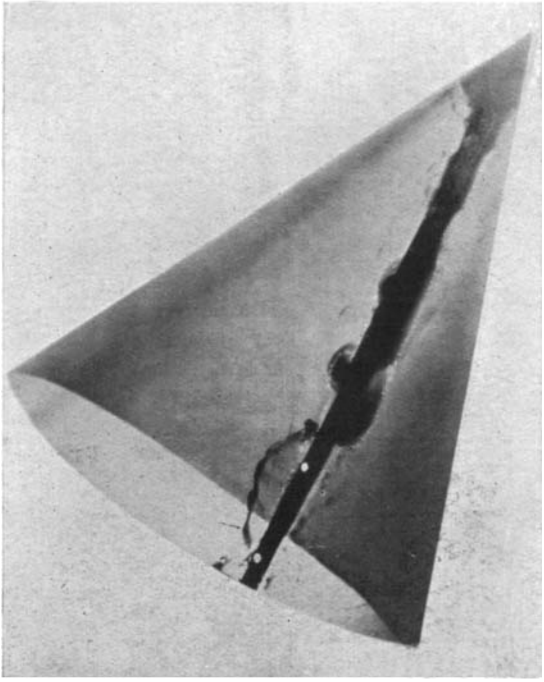

FIG. 17.

X RAY PHOTOGRAPH OF END OF STEEL PETROL-TANK OF AN AEROPLANE. SHOWING DEFECTIVE RIVETTING AND SOLDERED SEAM.

are outfits already on the market which can readily be moved from place to place. A wall-plug giving a supply of alternating current and a darkened room would meet most of one's requirements, and the necessary plant could be installed at moderate cost at factories and certain fixed centres. The timber parts could be rapidly passed in front of the fluorescent screen, and any object of interest or suspicion could be photographed if desired.

We should like to take the opportunity of thanking General Bagnall-Wild for his great interest in this work.

SUMMARY.

The best workmanship and the highest quality of material are essential in aircraft construction and the paper describes a method of examining aeroplane timber parts by X-rays, which the Aeronautical Inspection Department, with the co-operation of the Staff of the X-ray Department of the Cancer Hospital, investigated during the war.

No difficulty is experienced in detecting concealed knots, resin pockets and grub-holes. Excess or deficiency of glue in glued joints is readily revealed. Workmanship and material in the interior of completed laminated or box spars and struts cannot be scrutinised by ordinary methods of inspection, but every detail is shown up by the X-rays. The centre veneers of plywood (which enters into the structural design of many aeroplanes) can be examined by the same means.

In almost all instances fluorescent-screen examination suffices.

The paper gives particulars of some twenty or thirty actual examples collected during the war.