Indexed as:

Canada (Attorney General) v. Boeing Co.

Between
The Attorney General of Canada, plaintiff, and
The Boeing Company and Boeing of Canada Ltd., defendants

[1998] O.J. No. 2090

79 A.C.W.S. (3d) 1285

Court File No. 6176/79

Ontario Court of Justice (General Division)

G. Morin J.

May 21, 1998.

(89 pp.)

Contracts -- Performance or breach -- What constitutes a breach -- Torts -- Negligence -- Standard of care, particular persons or relationships -- Repairer of chattels -- Defences -- Contributory negligence -- Damages -- Contracts -- Breach of contract -- Special circumstances -- No market value -- Torts -- Torts affecting goods -- Damage to goods -- Measure of damages.

Action by the Canadian Department of National Defence for damages sustained by the DND when its helicopter crashed. DND alleged that the crash occurred as a result of Boeing's breaches of its contractual obligations and its negligent breach of its duty of care. The crash was caused when one of the helicopter blades cracked during flight. The blades were purchased from Boeing Canada and were the subject of an on-going maintenance program on the part on DND personnel in accordance with directions issued by Boeing. Part of the maintenance was that the blades were regularly x-rayed to determine if they were damaged. Boeing became aware that there was an increased possibility of the blade cracking if there was corrosion on the blade. This information was communicated to DND. However, DND failed to communicate this information to its maintenance staff and Boeing failed to communicate this to its maintenance staff. DND x-rayed the blade as part of their regular maintenance program at their Greenwood base. The x-ray showed corrosion damage which included a deep pit which eventually became the site of the crack. However, no Unsatisfactory Condition Report was issued by Greenwood. The blade was then sent to Boeing USA for its regular maintenance check. At the time of the maintenance check, the upper echelons at Boeing were aware of the connection between corrosion and cracking but failed to relay this information to their maintenance staff. The Boeing maintenance personnel noticed the corrosion and removed it. However, the staff did not inspect or test to determine whether there might be a crack underneath the area of corrosion. The Boeing Rotor Blade Inspection and Repair Manual required Boeing to conduct magnetic particle inspection of reworked areas of the blade during the course of its regular inspection. Boeing argued that it was not liable for breach of contract since the Manual was not part of the contract and the DND quality assurance officer signed off on the planning order that failed to require non-destructive testing of the reworked area.

HELD: Action allowed but DND was 50 per cent liable. DND was negligent in failing to adequately instruct its technicians with respect to the significance of corrosion on the blade and in failing to ensure that the x-ray review was properly conducted. This negligence contributed to the eventual failure of the blade and loss of the helicopter. Boeing Canada was in breach of its contract because it failed to ensure that the reworked area on the blade was examined by way of magnetic particling following the rework as required by the Manual. Boeing USA was negligent in failing to apply non-destructive testing to the reworked area after removing the corrosion to determine if there was an underlying crack. Boeing Canada's breach of contract and Boeing USA's breach of its common law duty contributed to the ultimate failure of the subject blade and the loss of the subject helicopter. In terms of apportionment, damages were contributed to equally by the plaintiff and the defendants. In terms of damages, there was no resale market for the helicopter at the time of its loss. The damages were based on the cost of its acquisition plus a reasonable appreciation factor until the time of its loss.

Counsel:

Derek G. Nicholson, for the plaintiff.
K. Scott McLean, for the defendants.

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1 **G. MORIN J.**:-- This action involves a claim for damages sustained by the plaintiff when a helicopter owned by it crashed during a flight near the City of Edmonton, Alberta, on March 19, 1974. The helicopter, which was completely destroyed, crashed when one of its rotor blades broke during flight. The plaintiff alleges that the crash occurred as a result of the defendants' breaches of duty of care both contractual and tortious.

2 The defendant, The Boeing Company, is a corporation incorporated pursuant to the laws of the State of Delaware. The Boeing Vertol Company, referred to in much of the documentation, is an unincorporated division of the defendant, The Boeing Company. For ease of reference the defendant The Boeing Company and The Boeing Vertol Company will hereinafter be referred to as Boeing U.S.A.

3 The defendant Boeing of Canada Ltd. was a corporation incorporated pursuant to the laws of Canada and was a wholly owned subsidiary of Boeing U.S.A. There is presently before me a motion brought on behalf of the plaintiff to amend the title of proceedings in the within action. The materials filed in that motion indicate that Boeing of Canada Ltd. was effectively liquidated in 1986 and that in terms of Boeing's Canadian entity, two Ontario corporations remain relevant namely Boeing of Canada Inc. and 692567 Ontario Limited.

4 It was agreed between counsel that the plaintiff's motion for amendment would be heard, if necessary, following judgment in this action. In these Reasons Boeing's Canadian entity will be referred to as Boeing Canada.

5 Over the course of the years several Crown agencies were involved with the defendants in the acquisition and servicing of the helicopters and their component parts. For the sake of simplicity, I propose to refer to the main Canadian actor in these relationships as the Department of National Defence (DND).

HISTORY

6 Pursuant to an Agreement dated February 14, 1963, DND purchased from Boeing U.S.A., twelve CH-113A helicopters. The helicopters were delivered by Boeing U.S.A., completely ready for flight, at a unit price of $696,612 U.S. The Agreement also called for the provision of training by Boeing U.S.A. to DND personnel and for the delivery by Boeing U.S.A. to DND of various technical publications.

7 Each of the helicopter rotor blades was designated by its own serial number. One of the blades bore the serial number A-1-177. During the course of operations the blades were routinely interchanged among the various helicopters depending on the needs of the day. It was blade A-1-177 that failed on March 19, 1974 causing the crash of the helicopter. It perhaps should be noted that any given point on a blade is measured in inches from the hub toward the end of the blade and this particular blade failed at point 171.2, some 59.4 hours following its inspection and repair by Boeing U.S.A.

8 It is clear on the evidence that following delivery of the helicopters in 1964 the helicopter blades were the subject of a comprehensive maintenance program on the part of DND personnel. The inspections were being

performed in accordance with directions given by Boeing U.S.A. by way of service bulletins that were being issued from time to time. Exhibit 4 in these proceedings contains all of the service bulletins that were issued by Boeing U.S.A. The role of DND personnel in terms of maintenance of the rotor blades was primarily that of inspection by way of x-rays. Effective September 1968 there was a Boeing U.S.A. comprehensive manual entitled Rotor Blade Inspection and Repair Manual No. 107-601. On the evidence, it is clear that the vast majority of the repairs specified in 107-601 were beyond the capabilities of DND and for such repairs to be effected it was necessary to return the blade to the Boeing U.S.A. plant.

9 When the helicopters were first purchased x-rays were performed on the rotor blades infrequently and on only portions of the rotor blades. As time went on, the frequency of x-ray inspections increased as did the area of coverage of the x-rays. The frequency of the x-rays would be adjusted by DND at the recommendation of Boeing U.S.A. following the coming to light of any specific problems relating to the failure of the rotor blade spars. For example, at Tab 5 of Exhibit 4, is Boeing U.S.A.'s Alert Service Bulletin No. A107-321 which would have gone to all of Boeing U.S.A.'s customers including DND. The bulletin is dated May 25, 1973 and bears the title Inspection Procedures for Crack Detection in Rotor Blade Spars (KHI, RSAF, RSN, and CF Aircraft). The reason for the issuance of the Alert Service Bulletin reads in part as follows:

> This requirement is the result of an H-46 rotor blade spar failure caused by a fatigue crack originating at a lap type defect. Six H-46 rotor blade spar cracks have been detected to date originating at lap type defects.

10 Under the heading Description the Alert Service Bulletin reads as follows:

> This Service Bulletin provides information for inspecting blade spars for serviceability using magnetic leakage field (MLF) equipment, eddy current equipment, or x-ray equipment.

11 In the Bulletin Boeing U.S.A. recommended x-ray inspection of the blade spar to be initiated immediately at the intervals determined by crack detection capability, air speed, and gross weight limitations. For a capability to detect a through crack in the heel radius of a total length of 0.10 inch and using a VNE of 125 knots at a gross weight of 19,000 pounds or less, Boeing U.S.A. recommended inspection every seventy hours.

12 As it turned out, it was this recommendation that was in place at the time of the crash on March 19, 1974. I am satisfied on the evidence that at the material time the DND x-ray technique had the capability of detecting a through crack of a total length of 0.10 inch, that the appropriate x-ray periodicity was seventy hours and that to the knowledge of the defendants and with their tacit approval, DND had increased the periodicity to seventy five hours to accommodate other work that had to be done on the blades at that interval.

13 The evidence discloses that between June of 1967 and April 1969, five Boeing rotor blades had failed in flight resulting in the destruction of the helicopters of which they were a part, the failures resulting from cracks emanating from different sources including corrosion. As a result of the problems relating to the failure of the blades, DND and Boeing U.S.A. entered into discussions beginning in the Spring of 1970 with a view toward establishing a revised system for the inspection and sampling of the blades. The Agreement entered into between the parties with respect to this new program is comprised of three pieces of correspondence exchanged between the parties. It is worthwhile to set out in some detail the correspondence.

14 By letter dated June 11, 1970 from Boeing U.S.A. to DND, Boeing U.S.A. referenced a meeting in Ottawa on May 1, 1970 between DND and Boeing U.S.A. and stated in part the following:

> In the course of the reference (a) meeting, you requested reconsideration of the CH-113/113A rotor blade sampling program. This letter presents Boeing's recommendations for inspection and sampling of CH-113/113A rotor blades.
>
> The original blade sampling program considered that each user subjected the 107-II series helicopter to dissimilar environmental and utilization conditions. The recommended sampling program for each user consisted of the following:
>
> (1) A complete teardown inspection of one (1) forward and one (1) aft rotor blade at one thousand (1000) hours.

(2) An overhaul inspection of three (3) forward and three (3) aft rotor blades at one thousand (1000) hours.
(3) Repetitive like inspections on selected rotor blades every five hundred (500) hours thereafter.

Based on the results of the sampling program plus data gathered from other customers, Boeing now recommends the following program for 107 II series rotor blades:

(1) Perform at a depot level facility:

(a) A special inspection of each rotor blade every two thousand five hundred (2500) hours or every four (4) years since compliance with Service Bulletin 107-282 whichever first occurs.
(b) Complete teardown sampling inspection of blades which are damaged beyond repair and whose past service use would further complement the sampling data.

The two thousand five hundred (2500) hour/four year inspection consists of:

(1) Boroscope inspection of the spar.
(2) Magnetic Perturbation Inspection in accordance with Service Bulletin 107-288.
(3) Magnaflux inspection of spar root end.
(4) Magnaflux inspection of root end socket.
(5) Overall visual inspection of entire rotor blade performing repairs as necessary.
(6) Root Box inspection in accordance with Service Bulletin 107-282.
(7) Removal of three (3) boxes outboard of box five for corrosion inspection. Box removals could include those needing replacement and/or repair due to damage or a discrepancy.

Condition reports shall be prepared by Boeing and added to sampling data from blades subjected to corrosion inspections, rework and modification programs further complementing the sampling data.

The above recommended inspection results will be progressively monitored by Boeing to determine whether changes to this program are necessary.

The analysis of data collected from the original sampling program and other sources has made possible this revision to the current inspection and sampling plan. Service Bulletins and 107 II publications will be revised as necessary to reflect the above inspection requirements. It should be noted that blades are not overhauled; they are periodically inspected and, when necessary, repaired.

15 By letter dated December 8, 1971 DND wrote to Boeing Canada as follows:

Boeing letter file 8-7995-134 dated 11 June 1970 advised, in response to a query raised at a Boeing-Vertol/Canadian Forces meeting Ottawa, on the 1 May 1970, that the life of P/N 107R1202 and A07R1202 rotor blades could be extended to 2500 hours or four years from date of compliance with Service Bulletin 107-282 but that these rotor blades would have to undergo a "relife" inspection before further TBO (time between overhauls) increases could be authorized.

In view of the number of rotor blades of both types which have undergone inspection, during the process of complying with the requirements of Service Bulletin 107-282, it is requested

that you:

a. Confirm the validity of the inspection requirement outlined in the referenced letter;
b. Provide an estimate of the cost of accomplishing the proposed "relife" inspection assuming no repairs are required;
c. Advise as to the length of time required for accomplishment of the "relife" inspection; and
d. Advise as to whether or not a Service Bulletin has or will be issued to detail the requirements of the "relife" inspection.

It should be noted that that letter was copied to Boeing U.S.A. It should also be noted that perhaps the most pertinent inquiry by DND contained in this letter in terms of this action is inquiry d. as to whether or not a Service Bulletin would be issued to detail the requirements of the "relife" inspection.

16 The final letter in the exchange is that dated March 3, 1972 from Boeing Canada to DND which reads as follows:

> Boeing of Canada Ltd., Vertol Division, herewith submits its proposal, (Appendix "A") to carry out the subject effort as requested in your letter Ref (i).
>
> In reply to the questions raised in Reference (i) we wish to advise:
>
> (a) The inspection requirements outlined in Boeing-Vertol letter 8-7995-1-134 dated July 11, 1970 and described in this proposal are valid.
> (b) The estimated cost of accomplishing the proposed inspection assuming no repairs are required is $3,500.00 each blade. (This price contains a Boeing-Vertol laid down cost of $3,125.00 plus current Boeing of Canada markup of 12% and is valid for all blades received during 1972.) Federal Sales Tax and Duty are extra if applicable.
> (c) The length of time required for accomplishment of the subject inspection is approximately 120 days.
> (d) A Service Bulletin is not required and will not be issued since the instructions are already set forth in the 107-6 Maintenance Schedule.
>
> We trust our proposal is complete, however should further information be required it will be forward promptly.

17 It is to be noted that in the letter Boeing Canada advises that a Service Bulletin will not be issued since instructions were already set forth in the 107-6 Maintenance Schedule. Appendix "A" enclosed with the letter reads as follows:

ROTOR BLADE PROPOSAL CAP-5312

Reference: (a) BV-107 Rotor Blade Inspection and Repair Manual 107-601 dated September 1968

(b) BV Service Bulletin 107-282 and 107-282B Rotor Blade Spar Inspection -- Root Box Area and Root Box Sealing Modifications
(c) BV Service Bulletin 107-288 and 107-288C Rotor Blade Spar Inspection

A. PURPOSE:

To determine continued serviceability of the CH113 and CH113A rotor blades and accu-

mulate historical data to support possible revision of the current inspection period, a special inspection shall be performed on each rotor blade every 2500 hours or every four years since compliance with Service Bulletin 107-282 whichever first occurs.

B. WORK DESCRIPTION:

The proposed inspection will encompass the following in compliance with the reference (a), (b) and (c) instructions:

1. Boroscope inspection of the spar.
2. Magnetic Perturbation Inspection.
3. Magnaflux inspection of spar root end.
4. Magnaflux inspection of root end socket.
5. Overall visual inspection of entire blade. (Any repairs required as a result of this inspection will be separately negotiated prior to performing work).
6. Root Box inspection.
7. Removal of three (3) boxes outboard of box number 5 for corrosion inspection. Box removals could include those needing replacement and/or repair due to damage or a discrepancy.
8. Reassemble blade with four new boxes.
9. Teeter balance track.
10. Package and prepare for shipment.
11. Prepare condition report.

18 It should be noted that the first reference noted at the very top of Appendix "A" is:

(a) BV-107 Rotor Blade Inspection and Repair Manual 107-601 dated September 1968

19 To better understand the nature of the inspection and work to be done under the 2500 hour/4 year program, it would be helpful to shortly describe the construction of the rotor blade. The first step in the construction of the rotor blade in the Boeing plant is the receipt of a tapered steel tube from the supplier. The tapered steel tube is then shaped into a D spar and the outside surface is zinc plated to protect against corrosion. The zinc as well provides a good surface to bond subsequent parts to the spar. A series of nineteen pockets are then constructed, each pocket consisting of four ribs and an aluminum skin. The pockets are often referred to as boxes as in Appendix "A" attached to the Boeing letter of March 3, 1972. Each pocket is then bonded in turn to the heel of the spar, box number 1 closest to the rotor end of the spar being known as the root box. A trailing edge is then secured in place connecting all of the pockets to the root box. In the case of the subject rotor blade A-1-177, a de-icing blanket was bonded to the leading edge of the spar and a protective metal strip was then placed over the de-icing blanket at the leading edge of the spar.

20 On February 5, 1973 the subject blade underwent the required 75 hour periodic x-ray examination in Summerside, Nova Scotia, where it was then located, by a DND non-destructive testing (NDT) unit located in Greenwood, Nova Scotia. The unit was composed of both senior and junior radiographers. Stanley Burke, who was an NDT technician at Greenwood at the material time, in his evidence explained that usually three or four of the technicians from Greenwood would go up to Summerside to x-ray perhaps six blades and one can infer from the evidence that this was the situation on February 5, 1973. Often the unit would leave Greenwood at 9:00 a.m. and work until 2:00 or 3:00 a.m. the next day at Summerside to finish the x-ray inspections before other work in the hangars started up the next morning. The method of x-ray inspection was as follows. The subject rotor blade would be placed in two V shaped dollies to hold it in a vertical position. The x-ray machine was kept in a fixed position and the blade was moved on the dollies past the x-ray machine for each shot. A tape was placed on the floor in order to keep the appropriate focal distance between the x-ray machine and the blade. At each position x-ray film would be placed on the spar, the exposure timer set, and the x-ray machine turned on for the required period of time, which period varied according to the thickness of the blade at any given position. The x-ray machine would then be turned off. The blade would be moved on the dollies so that the next position was opposite the x-ray machine. The film would be placed on the spar and the whole cycle would start over again. The x-rays of the subject blade taken on February 5, 1973 at Summerside were taken back to

Greenwood by the NDT unit to be developed and read there. Upon developing and examining the x-rays taken of the subject rotor blade, the NDT unit at Greenwood concluded that the blade was serviceable and it was in fact put back into service at Summerside as a spare.

21 With respect to the 2500 hour/4 year inspection to be conducted by Boeing U.S.A., I heard evidence from William Clark who at the material time was employed by DND as a maintenance specialist. He had, at that time, significant experience in helicopter maintenance having begun his training and work experience in 1957. Mr. Clark, from his office, controlled 120 blades with respect to the 2500 hour/4 year inspection and it was he that ordered the subject blade back to Boeing U.S.A. pursuant to the four year requirement of the program. At the time that Mr. Clark arranged for that order to issue on March 16, 1973, he was not aware that the blade had been x-rayed by the NDT unit at Greenwood. The subject blade was received by Boeing Canada in Arnprior, Ontario on April 3, 1973. Two tags were enclosed with the blade, neither of which gave any information as to the radiographic history of the blade.

22 Boeing Canada then in effect "subcontracted" the 2500 hour/4 year inspection to Boeing U.S.A. See Exhibit 2, Tab 130, a contract between Boeing Canada and Boeing U.S.A. dated April 10, 1973 whereby the subject blade was shipped to Boeing U.S.A. for the 2500 hour /4 year inspection at a cost not to exceed $6500. Ernie Sutton was the DND Detachment Commander at Arnprior at the material time. He gave evidence at this trial and explained that Boeing Canada's only involvement with the 2500 hour/4 year inspection was to receive the blade and ship it on to Boeing U.S.A. for inspection and work if required. He explained that the DND contract was with Boeing Canada and that Boeing U.S.A. was essentially a subcontractor. He explained as well that the upside cost of $6500 was expressed in U.S. dollars to Boeing U.S.A. and did not include the $1000 that Boeing Canada was paid for its involvement. He explained further that the final cost to DND on this particular 2500 hour/4 year inspection and work thereunder was some $10,493 U.S., the excess cost, it appears, having been readily authorized by DND.

23 The subject blade was received by Boeing U.S.A. in May 1973 and was inspected and repaired by Boeing U.S.A. over a period of months from that date. On October 1, 1973 the blade was shipped from Boeing U.S.A. back to Boeing Canada in Arnprior.

24 After the blade was received in Arnprior on October 23, 1973 with a certificate from Boeing U.S.A. as to serviceability and air-worthiness, it was then, on December 5, 1973, shipped to Canadian Forces Base in Edmonton on the orders of Mr. Clark. The subject blade was sent to CFB Edmonton to replace a blade with longer x-ray periodicity that was required to be sent to Search and Rescue on the British Columbia coast. The subject blade was x-rayed at Edmonton on January 9, 1974. Mr. Clark explained that this x-ray was performed at Edmonton in order to put the subject blade in the same sync as the other five blades that would be on the helicopter with it with the result that all six blades would come due for the next inspection at the same time. The NDT report dated January 9, 1974 arising out of the x-raying of the subject blade was for the specific purpose of determining whether a crack existed in the D spar of the rotor blade and the report's conclusion was "No defects indicated". The NDT report can be found at page 82 of the report of the Board of Inquiry into the accident. (Tab 193, Exhibit 2)

25 Following this x-ray inspection the subject blade was put into service and failed after 59.4 flight hours following the 2500 hour/4 year inspection and repairs effected by Boeing U.S.A.

CAUSE OF THE FAILURE

26 In this respect the court heard evidence from Dr. David Laister, Dr. Robert Waldron and professional engineers Douglas Romilly and Norman Crawley.

27 Dr. Laister received his Bachelor of Science (Honours) in metallurgy at the University of Wales in 1966 and received his doctorate from the same university in 1969. He was a research fellow at Queens University from 1969 to 1971 and a research officer with Bell Northern Research from 1971 to 1972. He was an engineer in the DND Failure Laboratory from 1972 to 1973 and the supervisor of the DND metallurgical laboratories from 1973 to 1976. From 1976 to 1981 he was a section head in DND and the superintendent of the DND Quality Engineering Test Establishment from 1985 to 1991.

28 Dr. Laister, following the crash, prepared a metallurgical and failure analysis of rotor blade A-1-177 with assistance from a number of people in the metallurgical lab and flight accident investigation lab at Quality Engineering Test Establishment (QETE) Department of National Defence. Dr. Laister's report was marked as Exhib-

it 53 in these proceedings. A Boeing representative, Mr. Jack Clark, who was also a metallurgist was present at QETE through almost the entire investigation and sat along side as the work was done. Dr. Laister had the entire set of x-rays from both Greenwood and Edmonton and Mr. Clark had access to those x-rays and indeed had access to everything that Dr. Laister accessed. Dr. Laister's evidence and opinions which, unless otherwise indicated, I accept, disclosed the following.

29 Initially, only the inboard section of the subject blade was sent to QETE. The outboard section of the subject blade was eventually found a substantial distance from the crash site and was then shipped to QETE. In examining the inboard section of the subject blade it was clear that there was an area of very evident corrosion that had gone completely through the bottom wall of the spar. Photograph 21 in Dr. Laister's report clearly shows the corrosion eye. The section including the corrosion eye was cut out and prepared for inspection by electronic microscope. Photograph 23 in the report shows the corrosion cracking on the fracture face at the approximate mid point toward the outer surface of the corrosion eye. In Dr. Laister's view the corrosion had existed for a significant period of time. Dr. Laister observed that immediately adjacent the corrosion eye there was no evidence of fatigue cracking but such evidence did exist further out on either side of the corrosion eye. The doctor explained that this indicated the propagation of the crack as it worked its way along the blade.

30 The blade was stripped of paint and evidence of reworking was discovered at the failure location. The area of rework on the inboard section at the failure location was approximately 4 inches by 3 1/2 inches. It was clear to Dr. Laister that the area had previously been shot peened at Boeing U.S.A. The metal was examined for metallurgical inconsistencies and no abnormalities were found.

31 Dr. Laister then examined the Greenwood x-ray and observed evidence of corrosion pitting at the failure location. He examined the Edmonton x-ray and found no such evidence. Dr. Laister explained that by x-raying the inboard portion of the blade he was able to line up the structures of corrosion, pitting and cracking with the Greenwood x-ray and was then able to detect that there was a crack showing in the Greenwood x-ray and that there was also showing in that x-ray, a corrosion pit that was associated with the crack.

32 Dr. Laister concluded that corrosion was a major factor in the crack leading to the ultimate failure of the blade in flight. He explained that for such a crack to develop there must be a corrosion environment and a load on the spar. The crack propagates when the corrosion medium sharpens the crack front and grows through the stress applied and through the corrosive medium.

33 Dr. Laister, in looking at the original Greenwood x-ray, was able to see the corrosion pit and the crack emanating from it. He went on to explain that the final catastrophic failure was proceeded by fatigue cracking. It was his opinion that the "pre-crack" leading to the fatigue cracking, was created by a corrosion pit. As he explained it, the sequence is as follows. A corrosion pit develops into a stress corrosion eye which progresses to fatigue crack propagation which results in ultimate failure.

34 It was Dr. Laister's opinion that the subject blade was cracked at point 171.2 prior to being shipped to Boeing U.S.A. for the 2500 hour/4 year inspection.

35 It was Dr. Laister's evidence that it was patently obvious that all of the corrosion had not been removed by Boeing U.S.A. during the 2500 hour/4 year inspection and rework and that corrosion products were still evident on the blade when he examined it following the crash.

36 Again, the doctor was quite satisfied that the ultimate failure of the blade originated from the crack site that is disclosed in the Greenwood x-ray. He explained that the crack was visible in the Greenwood x-ray because of the corrosion products existing there which occupied a greater volume than the material from which they came and therefore forced the crack apart.

37 It was Dr. Laister's opinion that in June of 1973 when Boeing U.S.A. was reworking the blade, the length of the crack was at least 0.158 inches.

38 It was Dr. Laister's view that having completed the reworking, Boeing U.S.A. would be able to visually determine if all surface corrosion had been removed but not whether any through corrosion existed. For that purpose in Dr. Laister's view, magnetic particling would have been the obvious choice.

39 Dr. Waldron has his Bachelor of Applied Science in Metallurgical Engineering and graduated from the University of British Columbia in 1970 with his doctorate in Metallurgical Engineering. He first became involved

in aviation matters in 1974 investigating aircraft accidents and component failures and has worked in that field exclusively since that time, having investigated at least 500 occurrences involving failures of aircrafts or components. In his work he deals with non-destructive testing issues on a routine basis and is familiar with all NDT investigations.

40 Dr. Waldron for the purpose of this trial, prepared an extensive report (Exhibit 73) with respect to the in-flight breakup of the helicopter and more specifically with respect to the ultimate failure of the subject blade.

41 Dr. Waldron in his evidence, which I accept, explained generally the principle of residual stresses and their relationship to fatigue. He likened it to taking a piece of coat hanger and repeatedly bending it in one direction and then straightening it out. When the coat hanger is bent there is tension on the top and compression on the bottom. If one keeps doing this to the coat hanger, eventually it breaks in two. He explained that before failure occurs there must be three factors:

1. alternating stresses;
2. part of the stress must be tension; and
3. the severity of the stressing must be above a certain level.

With these three factors in play eventually a crack develops on the tension side of the material being stressed, the crack propagates, and then the material fails. He also explained that 80 to 90 per cent of the alternating stressing goes to initiate the crack and upon initiation it relatively quickly goes on to propagation and failure.

42 The doctor explained that there were ways to extend the life of a piece that may be under alternating stress by way of tension and one of those ways is to apply residual compressive stress as a layer on the material. This may be achieved by shot peening the surface to create residual compressive stresses at the surface. It was the doctor's understanding that following any rework it was Boeing U.S.A.'s practice to restore surface residual compressive stresses through shot peening.

43 The doctor then went on to explain the effect of corrosion in connection with residual compressive stress. He explained that if a corrosion pit enters into the surface deeper than the layer of residual compressive stress, three negative things occur. Firstly, the applied residual compressive stress does no good at all and all the effect of it is lost. Secondly, the 80 to 90 per cent of alternating stress to begin the crack is not required, the need for it being reduced and perhaps eliminated and thirdly, there is a stress concentration.

44 The doctor was aware of Boeing's position that the initiation and propagation of the spar fatigue crack was the direct result of the loss of compressive residual stresses and that on the basis of its measurements Boeing had concluded that the spar was buckled or dented in the area of the failure origin by "flapping" of the blade. He understood the Boeing theory to be that at some point in time prior to the crash, the blade had been stressed up to a level where it lost all residual compressive stress and probably established tensile stress. The doctor noted that there was no recorded evidence of any flapping incident involving the subject blade and also that in virtually all cases where flapping leads to failure, the failure is at station 63, a point where the spar goes from being straight to a D shape. The doctor noted that history shows that station 171 is not expected to fail in the case of an incident of flapping.

45 Finally, Dr. Waldron was of the view that Boeing's theory did not stand up in the face of the documents that were filed as Exhibits 62 and 63. Exhibit 63 detailed the residual stress data on the outer surface of the spar including the area reworked by Boeing U.S.A. during the 2500 hour/4 year inspection. The doctor noted that the residual stress measurements in the reworked area would be of little value because those stresses would have been changed at the time of reworking. However, Exhibit 62 displays the residual stress data on the inner surface of the spar which had not been reworked. If one compares Exhibit 62 to Exhibit 63 one sees two very different patterns. On Exhibit 62 all of the unacceptable stress measurements are on the inboard section of the spar while all of the compressive stress measurements along the edge of the failure on the outboard portion of the spar are well in excess of acceptable limits. It was the doctor's view that this was totally inconsistent with the loss of compressive residual stress causing failure at that point. The only conclusion that the doctor could reach that was before the crash the residual stresses were normal and did not cause failure. The unacceptable residual compressive stress measurements on the inboard section of the spar in the doctor's view occurred after failure as a result of the crash itself.

46 In conclusion, it was the doctor's view that the blades residual stress pattern was normal before the crash

and that operational stresses were normal. There existed, however, corrosion damage including a deep pit which eventually became the site for the fatigue crack. The pitting likely extended completely through the effective thickness of the surface compressive stresses thus eliminating all of the beneficial effects of the surface stresses. He was also of the view that the pre-existing fatigue crack was in the area of corrosion damage reworked by Boeing U.S.A. during the 2500 hour/4 year inspection and that the pre-existing fatigue crack was not visually detectable.

47 On the issue of causation I also heard evidence from professional engineers Dr. Douglas Romilly and Norman Crawley. Their evidence was consistent with the evidence given by Doctors Laister and Waldron.

48 Dr. Romilly, who obtained his PhD in Mechanical Engineering in 1984 from the University of Waterloo with a thesis related to fatigue and fracture, gave in his evidence a short explanation as to crack formation. The first stage in crack formation is the initiation stage. The crack begins to form on the surface of the component where the stress concentration is highest. Anything that changes the shape of the surface will produce stress concentration. The second stage in crack formation is propagation, that is, the crack begins to grow. The third stage of crack formation is when the stress has become too large and the component comes apart. One factor which can greatly affect fatigue crack growth predominately in the initiation phase is the presence of surface anomalies which are discontinuities in the surface of the material causing a localized stress concentration which in turn provides a preferred site for a fatigue crack to initiate. The introduction of any form of discontinuity will cause stress in the region to concentrate or increase in magnitude above the original stress level within a relatively localized area adjacent to the discontinuity. One such surface discontinuity is a corrosion pit and such a corrosion pit will serve to concentrate the stresses at its site. The doctor explained that a corrosion pit is a localized region which has undergone a chemical reaction or breakdown of the material such that material has been removed by the corrosion process. This loss of material forms a void or pit on the surface of the material and as this pit is an anomaly or sharp discontinuity on the material surface, it will act as a stress concentration. Corrosion pits are especially detrimental because they act both to accelerate the fatigue crack initiation and propagation process as well as increasing the probability of premature fracture at the location.

49 Dr. Romilly dismissed Boeing's theory that the ultimate failure of the subject blade occurred as a result of excess flapping. His evidence in that respect which I accept was consistent with that of Dr. Waldron.

50 Mr. Crawley who is a professional engineer and who has his Masters Degree in Aerodynamics was also of the view that it was highly improbable that excessive flapping was a cause of the failure of the subject blade.

51 Finally, with respect to Boeing's flapping theory it should be noted that in his examination for discovery read in as part of the plaintiff's case, Isadore Senderoff, an officer of Boeing U.S.A., admitted that there were four repairs of the subject rotor blade in Boeing U.S.A.'s shop between 1967 and 1973 and Boeing at no time during the course of those inspections and repairs, observed any spar damage or other evidence of excessive flapping.

52 On all of the evidence I am satisfied that excessive flapping of the blade was not a contributing factor to the ultimate failure of the blade. I am satisfied on the evidence that the failure of rotor blade A-1-177 was caused by the initiation and propagation of a fatigue crack at station 171.2 on the bottom surface of the spar. The loss of residual stress as reported by Boeing was the result of post fracture impact damage of the spar and loss of residual stresses was not a contributing factor in the blade failure. I am satisfied that the primary causal factor in the fatigue failure was the presence of a corrosion pit which acted as the crack initiation site. The corrosion pit caused a significant reduction in fatigue life of the rotor blade due to three effects:

(a) extension of the pitting through the effective thickness of the surface compression stresses;
(b) stress concentration effects associated with pitting;
(c) shortened crack initiation stage of the fatigue process.

53 I am satisfied as well on the evidence that at the time of Boeing U.S.A.'s 2500 hour/4 year inspection a crack approximately 0.163 inches in length was present in the spar of the subject blade at station 171.2 and that the crack extended completely through the wall of the spar. The pre-existing fatigue crack was in an area of corrosion damage repaired by Boeing U.S.A. during the inspection and the pre-existing fatigue crack was not visually detectable.

THE GREENWOOD X-RAY

54 As will be seen from an eventual review of the evidence relating thereto, the x-ray of the subject blade at station 171.2 taken at Greenwood on February 5, 1973 by the DND NDT unit shows, at least if one knows where to look, evidence of corrosion and of a crack. It is known from the evidence that no Unsatisfactory Condition Report emanated from Greenwood at that time nor was there any record of any defect in the subject blade disclosed by this x-ray at the time that the blade failed in flight. It is known that the blade was put back into service following the Greenwood x-ray and therefore there is raised the issue of DND's own responsibility and liability for the blade failure and resulting helicopter crash. In order to properly analyze that issue, it is necessary to review in some detail the evidence as to the x-ray technique that was being used by the Greenwood NDT unit at the material time, the evidence as to the appreciation of the various players of the risk of corrosion in the blade spar at the material time, and the evidence with respect to what was actually seen by the Greenwood x-ray technicians when looking at the x-ray in Greenwood and what, in all of the circumstances, should have been seen by the technicians.

Technique

55 The x-ray technique developed by DND to be followed by its x-ray technicians was that designated as 7 GX REV 1 which became effective November 28, 1972 and was in place at the time of the Greenwood x-ray. The technique then progressed to that designated as 7 GX REV 2 which became effective June 19, 1973 and was in effect at the time of the Edmonton x-ray. I heard from the two DND personnel who were primarily responsible for the revision of the x-ray techniques, namely Charles Chapman and John Tasseron.

56 Mr. Chapman enlisted in the Royal Canadian Air Force in July 1957 as a General Airframe Technician. He was involved in air craft maintenance from the date of his enlistment and from 1967 to 1972 he was at Canadian Forces Base Chatham where he was responsible for all non-destructive inspections of the fleet. In 1971 he participated in setting up a full NDT facility at Chatham including radiography, ultrasonic, eddie current, magnetic particle and liquid penetrant inspections. He was employed as an NDT technician and while at Chatham wrote and passed junior level ultrasonic, junior industrial radiography, magnetic particle and liquid penetrant categories. From 1972 to 1974 he was posted to Canadian Forces Base Trenton and was employed in the Development Section where he participated in the revision of x-ray technique 7 GX for the inspection of helicopter blades.

57 Mr. Tasseron is an NDT specialist. He joined the Canadian Forces in 1959 and began his NDT courses in 1971 taking training in liquid penetrant, magnetic particling, ultrasonic and radiographic inspection. He was certified by the Canadian Government Specification Board as Junior Radiographer in November of 1972 and was an NDT unit Course Co-ordinator at Trenton until July of 1976.

58 Mr. Chapman's evidence, which I accept, disclosed the following.

59 With respect to the x-ray technique developed for the helicopter blades, initially DND patterned its technique 7 GX on the technique developed by Boeing. DND felt, however, that the Boeing technique could be improved upon by doing such things as changing the direction of the shoot and removing the blades from the helicopter before the inspection in order to be able to put the film on both the top and bottom side of the blade. In the process of attempting to improve the technique the group purposely put scratches of a known depth on the blade, x-rayed, and determined that they had the capability of detecting a scratch that had a depth equal to two per cent of the thickness of the material being x-rayed.

60 7 GX REV 1 is located at Tab 99 of Exhibit 2. It notes that the purpose of the inspection is to detect discontinuities before they become large enough to cause failure of the blade. Under this technique the blade was divided into three sections namely from station 54 to station 60, station 60 to station 90 and station 159 to station 276. 7 GX REV 1 was similar to the Boeing technique except for the angles of shot and except for the fact that Boeing shot toward the leading edge of the blade while Canadian Forces shot toward the boxes.

61 Eventually, 7 GX REV 1 was replaced by 7 GX REV 2 which came into force on June 19, 1973. 7 GX REV 2 is located at Tab 137, Exhibit 2. 7 GX REV 2 has the same purpose as 7 GX REV 1. The revisions in 7 GX REV 2 included extended coverage with essentially all of the helicopter blade being x-rayed under this revision. Mr. Chapman and Mr. Tasseron met with the Boeing U.S.A. people at Philadelphia in October of 1973 and discussed with Boeing U.S.A. 7 GX REV 2. Boeing U.S.A. raised no concerns about the technique at that time or at any time prior to the crash of the helicopter.

62 With respect to the ability to detect a crack .1 inch in length, which was a criteria for the 75 hour inspection periodicity in place at the time of the crash, Mr. Chapman for the purpose of giving evidence at this trial, conducted a simple experiment. He took a piece of rotor blade and using a machine put a notch 100/1000 of an inch long and 5/1000 of an inch wide on the inside of the spar. Then, using the x-ray technique in place at the material time, he took x-rays and the notch showed up clearly. This satisfied Mr. Chapman that in retrospect at the material time, DND was able to ascertain a .1 inch long crack and therefore was able to go to the 70 (75) hour inspection periodicity.

63 It is interesting to note that in examination-in-chief Mr. Tasseron testified that in developing 7 GX REV 1 he had done tests to establish that artifacts of .1 inch in length could be seen on the film but that there was, in fact, no crack length standard set out for him by his superiors to work to at the time. He confirmed in examination-in-chief that DND at the time knew that the technique had a capability of detecting an artifact .1 inch in length with a thickness constituting two per cent of the thickness of the material being investigated. However, in cross-examination, in referencing the document at Tab 90, Exhibit 2, a Project Directive dated November 10, 1972 requiring a review of 7 GX to determine whether a higher degree of sensitivity in detecting cracks could be obtained, Mr. Tasseron was unable to say one way or the other whether 7 GX had a capability of detecting a crack .1 inch in length. He had never been asked to look at 7 GX to determine whether it had such a capability nor did anyone ever ask that question of him either with respect to 7 GX, 7 GX REV 1 or 7 GX REV 2.

64 I am satisfied on all of the evidence that the x-ray technique to be implemented by the x-ray technicians for periodic x-ray inspections of the spars and which were in fact implemented at Greenwood and in Edmonton were sufficient for the purposes as they then existed, were sufficient to warrant a 70 (75) hour periodicity based on the criteria established by Boeing, and that there were no deficiencies in the techniques that in any way contributed to the failure of the blade and ultimate crash of the helicopter and I so find.

65 As previously indicated in analyzing the extent to which DND's conduct may have contributed to its own loss and indeed in analyzing the defendants' obligations to the plaintiff in all of the circumstances of the case, it is important to determine the extent to which the parties had knowledge of the risk of corrosion existing on the spar surface.

Corrosion

66 Most, if not all, of the information relating to that risk originated with Boeing. However, it appears on balance from the evidence that that information was, to a substantial extent, conveyed by Boeing to the plaintiff and that at least by the time that the Greenwood x-ray was taken, DND and Boeing had about the same quantity and quality of information relating to corrosion and should have had about the same appreciation of the danger of corrosion as it related to cracks and the ultimate failure of blades.

67 Mr. Clark in his evidence recalled that following a helicopter crash in Sweden in 1968, caused as a result of failure of the helicopter blade, he received information from Boeing that the failure in the blade had been caused by a crack which had in turn been caused by corrosion on the blade. Mr. Clark referenced a minute of a meeting held on December 3 and 4, 1968 at Canadian Forces Headquarters (Tab 11, Exhibit 2) attended by roughly ten Canadian Forces personnel and ten Boeing personnel. At page 6 of the minute under the heading ROTOR BLADES reference is made to the Swedish crash being attributed to aft rotor blade failures caused by excessive corrosion in the root box area.

68 At Tab 19, Exhibit 2 is a letter from Boeing U.S.A. to the Chief of Defence staff dated April 4, 1969. This is Boeing's official announcement of:

> ... the major accident of a Swedish helicopter whereby the cause was determined to have originated from a corrosion pit in the heel of the rotor blade spar.

69 At Tab 89, Exhibit 2 is a Boeing document that lists all rotor blade failures that had occurred as of November 1972. It appears that this document was received by DND on November 20, 1972. Included among the crashes referenced in the document is the Swedish crash in September of 1968 where the spar failed in flight and the cause at page 10 of the report is listed as "corrosion". The document, at page 11 thereof gives the following direction:

> .BLADE SPAR FATIGUE CRACKS CAN RESULT FROM:

- manufacturing defects

- field or maintenance damage

- static overstress

- spar corrosion

70 At Tab 148, Exhibit 2 is a telex from Boeing U.S.A. to Boeing Canada with respect to the helicopter crash on August 20, 1973 in Japan. The telex is dated September 19, 1973 and the subject blade was still in the Boeing U.S.A. plant at that time. The telex reads in part as follows:

> ... The USN advised their investigation revealed the crash resulted from the failure of a forward rotor blade spar. Investigation of the failure by the USN at North Island determined a fatigue crack originated at a corrosion pit located on the heel of the spar adjacent to the inboard rib of the root box ...

The telex goes on to read as follows:

> It is recommended that prior to further flight all model 107 rotor blades (the subject blade was a 107) except those having ISIS installed be inspected for spar corrosion if the rotor blade has reached a total of 30 months from date of manufacture and has been operated more than 400 flight hours or no later than 48 months from date of manufacture with less than 400 flight hours. X-ray or magnetic perturbation inspection techniques may be employed to accomplish this inspection. X-ray procedures recommended are contained in para.ff. Subsequent to the initial inspection recommended above further identical corrosion inspections should be conducted yearly or each 200 flight hours whichever occurs first. The above recommended inspection replaces the current 2500 hour/4 year requirement to remove and replace the root box and 3 additional outboard boxes to sample spar condition for corrosion. A service bulletin will be released on this subject.

Mr. Clark during the course of his evidence pointed out that in October of 1973 when the subject blade was certified airworthy by Boeing, Boeing was aware of the Swedish loss caused by corrosion of the blade and the Japanese loss caused by corrosion. It is of interest to note that a review of Tab 136, Exhibit 2, Boeing U.S.A.'s work records relating to the subject blade during the 2500 hour/4 year inspection, shows at pages 6, 7 and 8 that the blade was subjected to magnetic perturbation on May 24, 1973. There is no indication on those pages that corrosion was found at station 171.2. As we shall see, it was only after removal of the de-icing blanket by Boeing that corrosion was visually observed.

71 It is of interest to note that the last alert bulletin issued by Boeing prior to the completion of the 2500 hour/4 years inspection and rework on the subject blade was dated May 25, 1973 (Exhibit 4, Tab 5). The title of that alert service bulletin is "Inspection Procedures for Crack Detection in Rotor Blade Spars". It is this alert service bulletin that set the criteria for a seventy hour periodicity x-ray inspection. However, on November 10, 1973 Boeing issued another alert service bulletin entitled "Inspection of Rotor Blade Spar for Corrosion" and included the following warning in the bulletin:

> Failure to comply with the instructions in this service bulletin could result in an undetected corrosion condition which could cause failure of a rotor blade spar and loss or damage of the aircraft.

It would appear that this is the service bulletin referred to in the telex from Boeing U.S.A. to Boeing Canada dated September 19, 1973.

72 At Tab 147A, Exhibit 2, is a "Rotor Blade Corrosion Inspection Survey" prepared by Boeing at the request of Mr. Sutton. This report was prepared in 1973, and lists some sixteen specific inspections that disclosed corrosion on the spars during the period 1970 to 1973. Mr. Sutton has no recollection of going through the report once it was received and would likely have forwarded on to NDHQ in Ottawa. He was never asked by NDHQ to follow it up in any way.

73 During the course of this trial I heard evidence from Stanley Burke. He was an NDT technician at Green-

wood during the period 1970 to 1974. He had been in the field of non-destructive testing from 1969 to 1984 and took his radiology training in 1971. This training included theory, heavy casting, material processing, wells, light forges and castings, interpretation and practical application. Mr. Burke was able to identify at Tab 99, Exhibit 7, 7 GX REV 1 and confirmed that that was the technique that was applied at Greenwood on the subject blade. He was aware that the purpose of the inspection was as set out at page 5 of 7 GX REV 1 and that was to detect discontinuities before they became large enough to cause failure of the blade. His definition of a discontinuity was anything that leads to or would cause failure of the blade and according to his evidence a discontinuity would include corrosion in some cases.

74 Mr. Tasseron testified that in 1973 if the NDT technician saw corrosion on the x-ray of a spar, it should have alerted him to the possibility of an underlying crack. Mr. Tasseron confirmed in his evidence that the purpose of the x-ray inspection of the blades was to detect discontinuities and that discontinuities included corrosion. He confirmed that 7 GX REV 1, the x-ray technique in place at the time of the Greenwood x-ray, was capable of revealing corrosion.

75 Dr. Laister in his report, Exhibit 53, at page 8 thereof, states in part:

> The Greenwood radiographs clearly indicate that the crack has associated with it a corrosion pit.

Then, in his conclusion he states the following:

> 10. It is felt that the discovery on the radiographs of the crack when examined at Greenwood could have been effected had the reader of the radiographs at that time been aware of the serious nature of corrosion on this component.

Initially during the course of cross-examination the doctor explained that with respect to that conclusion his opinion has changed since the date of report, April 1974, and that he does not now believe that the crack indication would have been discovered by the Greenwood technicians. He conceded however quite readily, that the corrosion was evident in 1974 when he viewed the Greenwood x-ray and it still strikes him as evident when he looks at the radiograph today. In further exchange with counsel for the defendants, Mr. McLean, I understood that the doctor was not necessarily standing back from conclusion number 10 in his report but rather was now saying that he was assuming in hindsight that in 1973 the technicians were not aware of the serious implications of the corrosion. He testified that as far as he could determine in 1973 technicians did not know of the association between corrosion and cracking. He was not, on cross-examination, prepared to go so far as to say that had the DND technicians been aware of the serious implications of corrosion they should have discovered the crack disclosed by the x-ray.

76 Mr. Isadore Senderoff gave evidence on behalf of the defendants. He was employed by Boeing and its predecessors from 1954 until he retired in 1994. He was employed firstly as an aircraft mechanic then became a service engineer then a senior service engineer and then assistant supervisor in service engineering and training. He was an air safety investigator from 1963 to 1969 when he became unit chief of system safety and human factors and in 1973 added reliability and maintainability to his responsibilities. He was manager of product assurance from 1974 to 1977 and from 1977 to 1991 was manager, system safety human factors survivability and vulnerability. Filed as Exhibit 78 was a list of approximately sixty helicopter crashes that Mr. Senderoff investigated during the period 1959 to 1993. Five of the crashes that he investigated involved blade failure and one of those five blade failures was caused by corrosion.

77 Mr. Senderoff in his evidence was able to address generally the quarterly meetings that were held between Boeing and Canadian Forces throughout the material time. By way of example, he pointed specifically to the minute at Tab 11, Exhibit 2, dated 15th January 1969 relating to the meeting held at Canadian Forces Headquarters on December 3 and 4, 1968 and acknowledged that this meeting had followed the helicopter crash in Sweden which had occurred on September 6, 1968. The minute, as previously indicated, under the heading "Rotor Blades 1. Crack Inspection evaluation techniques" notes that Boeing opened the discussion with an outline of the current status and stated that the crash of the Swedish helicopter was attributed to aft rotor blade failures caused by excessive corrosion in the root box area.

78 Mr. Senderoff went on to explain that from time to time Boeing would make special presentations to their customers. At Tab 29, Exhibit 2, is such a presentation dated September 22 to September 26, 1969 entitled "Joint Canadian/Swedish Program Review Rotor Blade Summary". This program review followed the Swedish

crash and was prepared for both Boeing's Swedish and Canadian customers. At page 4 of the presentation is a BLADE SPAR CORROSION SUMMARY comprising a summary of customer blades examined at Boeing and reporting on corrosion that was found on the blades. The conclusions on the following page with respect to spar corrosion point out that corrosion at the root box area is more prevalent and more extensive than at the outboard area but that occurrence at both locations is random. The conclusions point out as well that the severity and frequency of occurrence of corrosion is greater for aircraft operated near the ocean.

79 Mr. Senderoff referred to the report prepared by Boeing and presented to DND on November 20, 1972 (Tab 89, Exhibit 2) where it is indicated at page 13 thereof that blade spar fatigue cracks can result from spar corrosion.

80 During his evidence Mr. Senderoff referred to Boeing alert service bulletin A107-325 (Exhibit 4) dated November 10, 1973 which directs on the second last page thereof as follows:

> Reject the blade if any indication of corrosion or other defects is found. Blades rejected for positive x-ray indications shall be removed from service pending identification and disposition of the defect. Refer to the 107-601 rotor blade inspection and repair manual.

Again it should be noted that that bulletin was issued at about the time that the subject blade was still at Boeing U.S.A. Mr. Senderoff confirmed in his evidence that at that time Boeing knew that corrosion was serious and was now directing its customers to reject spars for corrosion. He conceded that at that time to Boeings knowledge corrosion could be a source of cracks propagating to failure.

81 On all of the evidence I find that the senior personnel of the plaintiff and defendant companies appreciated full well, as of the date that the Greenwood x-ray was taken, the inherent dangers of corrosion on the spar of the rotor blade and the very real risk that such corrosion could be an indicator of an underlying crack that could in due course propagate to ultimate failure. As will appear from a review of the evidence relating specifically to the Greenwood x-ray, there is a very real question as to whether or not that appreciation was ever passed on to the men in the field, in the plaintiff's case the x-ray technicians, and in the defendants' case, the technicians at the Boeing U.S.A. plant.

82 Bruce Snyder gave evidence on behalf of the defendants. He is 57 years of age. He is presently employed by Boeing U.S.A. as a Senior Manager, Product Quality Control. He has been employed by Boeing since 1960. In 1973 he was a first level supervisor in the blade shop at the Boeing U.S.A. plant. His job was to supervise inspections of blades, both those being manufactured and those already in use. This was the witness that was called by the defendants to testify as to the manner in which the subject blade was inspected and reworked by Boeing U.S.A. under the terms of the Agreement entered into between the parties with respect to the 2500 hour/4 year inspection. It was Mr. Snyder who addressed the fact that no non-destructive testing was done by Boeing U.S.A. on the reworked area of the spar of the subject blade following rework. That rework involved the removal by Boeing U.S.A. of corrosion that was discovered at the ultimate failure site of the spar after removal of the de-icing blanket. Mr. Snyder, during the course of his evidence made an interesting, if not shocking, disclosure. He testified that he did not know of nor had he been told by his employer about the crash in Sweden in 1968 and the crash in Japan in 1973 both of which resulted from failure of the blade as a result of corrosion. Mr. Snyder testified that he did not know that there could be a crack under existing corrosion. He was never told that by Boeing. He was never told by Boeing that cracks could develop from corrosion. More will be said about this when the question of the defendants' obligation under the contract for the 2500 hour/4 year inspection is discussed and when the defendants' duty of care to the plaintiff at common law is discussed.

The Taking and Viewing of the Greenwood X-Ray

83 Following the crash a Board of Inquiry was convened. The report is at Tab 193, Exhibit 2, and is dated March 31, 1974. One of its conclusions was that the subject rotor blade failure was caused by a fatigue precrack which originated at a stress corrosion site located on the lower surface of the blade spar. I may say in passing that I do not consider this stated conclusion to be evidence as to the cause of the subject rotor blade failure for the purpose of this trial and that I have reached my conclusions with respect to the cause independent of the report of the Board of Inquiry and based only on evidence at this trial. I note the Board's conclusion only as part of the overall narrative.

84 Following the report of the Board of Inquiry, the Department of National Defence, Quality Engineering

Test Establishment (QETE), sent a message to National Defence Headquarters under date April 3, 1974 indicating that the Greenwood radiographs taken February 5, 1973 had been received by the QETE laboratory and the laboratory had determined that the radiograph confirmed pitting corrosion and a four millimeter crack at the location of the failure. Mr. Clark in his evidence explained that while at the time of initial viewing of the x-ray on February 5, 1973 the Greenwood x-ray disclosed nothing, after the crash DND personnel were able to detect corrosion and a crack at the failed site because they knew where to look for it.

85 During the course of Mr. Chapman's evidence, the Greenwood radiograph was viewed on an x-ray viewing machine in the courtroom. The viewing machine was exactly the same as the one used at Greenwood in 1973. Mr. Chapman explained that x-rays are usually checked by the technician by going from side to side and from up to down with a magnifying glass although he advised that the use of a magnifying glass was not called for in any of the x-ray techniques. He explained as well that the Greenwood x-ray presently available is a copy and not the original. He explained that the scanning across and up and down of each radiograph usually takes perhaps ten to fifteen minutes. Looking at the Greenwood x-ray which was marked as Exhibit 7A, one could see tiny lines which were the wires of the de-icing blanket and one could also see spots of corrosion. There are arrows on this radiograph pointing to the particular corrosion pit with the crack in it and it was Mr. Chapman's evidence that if one did not know where to look on the x-ray, it would be almost impossible to discern the crack. On the other hand, Mr. Chapman testified that what the technicians were looking for under 7 GX REV 1 which was in place at the time of the Greenwood x-ray (and indeed under 7 GX REV 2 at the time of the Edmonton x-ray) were discontinuities not necessarily cracks. In other words according to Mr. Chapman, the technicians at the time of the Greenwood x-ray would have been looking for anything that might cause one to look further. 7 GX REV 1 points out that the purpose of the inspection is to detect discontinuities before they become large enough to cause failure of the blade and Mr. Chapman testified that a discontinuity is anything that breaks up the smooth flow of the part including corrosion. Mr. Chapman readily agreed on cross-examination that while there was no direction to look for corrosion in 7 GX REV 1 as such, corrosion would be included in the term "discontinuity".

86 In his evidence Mr. Chapman explained that when the subject x-ray was reviewed at Greenwood, the technicians would be required to follow the following procedure. There would be available an interpretation sheet with headings Exposure, Interpreter and Remarks. Under the heading Exposure there would be indicated the station on the blade where the x-ray was taken. Under the heading Interpreter the examining technician would be identified and under the heading Remarks would be the results of the reading of the x-ray. Mr. Chapman explained that before the final sheet was prepared, each reader would keep his own sheet to record what he was seeing on the x-rays and that there were always two readers. See Tab 103, Exhibit 2, page 5. Mr. Chapman went on to explain that if the remarks of each reader did not match then the readers would read the x-ray again at the appropriate station and if they agreed that there was something disclosed in the x-rays then everyone in the shop would have a look and another shot would probably be taken. If the technicians could not decide whether there was a defect disclosed on the radiograph then a report and the particular radiograph would go to the Non-Destructive Testing Centre (NDTC), Aircraft Maintenance Development Unit. NDTC would look at the report and the blade and the x-ray would be shot again if NDTC could not decide whether there was a defect. If NDTC could resolve the problem then an appropriate report would be sent to National Defence Headquarters in Ottawa which was in a position to overrule any resolution by NDTC. If there was no resolution by NDTC then it was up to Ottawa to make the decision whether to send the matter on to Boeing U.S.A. where Boeing U.S.A. would look at the Canadian x-rays and do its own investigation.

87 Mr. Chapman, during the course of his evidence, was not aware of the identify of the Greenwood technicians who took and read the Greenwood x-ray. He was aware that at the present time there was no interpretation sheet available with respect to the Greenwood x-ray and he personally had never seen such an interpretation sheet. He confirmed that a copy of the x-ray such as was available at this trial, is usually not as good as the original in terms of being able to pick up defects on the film.

88 On cross-examination Mr. Chapman conceded to counsel for the defendants that he was of the view, on looking at the Greenwood x-ray that the readers should have seen and probably did see the corrosion which would fall within the definition of "discontinuity" in the 7 GX REV 1 technique. Mr. Chapman added that the likelihood of a Greenwood reader seeing the corrosion was even greater if he was looking at the original x-ray which must have been the case.

89 Stanley Burke who was a radiograph technician at Greenwood from 1970 to 1980 could not assist the

court as to the identity of the technicians who took the Greenwood x-ray or as to the readers who examined it. He testified that he did remember the helicopter crash and as soon as Greenwood heard about it, all of the technicians went to the filing cabinet to dig out the subject blade's radiographs. Three or four of the technicians in the shop looked at the radiographs together. They viewed all forty of the x-rays of the blade to see if they could detect anything that would have caused a fracture of the blade and they all agreed that they could see nothing. At that point in time the technicians did not know where the fracture had occurred.

90 Mr. Burke explained a viewing procedure which was essentially consistent with that described by Mr. Chapman. According to Mr. Burke, once the x-rays were developed at Greenwood one technician would read the x-rays and make his notes on the interpretation sheet previously described. The first reader could be either a senior or junior technician. The second reader was always a senior technician. The first reader would view all of the x-rays and make appropriate entries on the interpretation sheet. The x-rays would then be passed to the second reader together with the first reader's rough sheet. The second reader would view the x-rays and see what the first reader had said on his sheet. If the second reader agreed, then a final sheet was prepared in accordance with the first reader's rough sheet. If there was not an agreement there would be a discussion between the first and second reader and if it could not be resolved at that level, then someone else would be brought in to conduct a third reading. Mr. Burke advised in his evidence that anything that the two readers were not sure of would be reported to their supervisor to start the process of making up an Unsatisfactory Condition Report (UCR).

91 Mr. Burke was familiar with 7 GX REV 1. He was aware that the purpose of the inspection was as set out at page 5 and that was to detect discontinuities before they became large enough to cause failure of the blade. His definition of a discontinuity was anything that leads to or would cause failure of the blade and a discontinuity according to him would include corrosion in some cases. It was his evidence that he had viewed the Greenwood x-ray with plaintiff's counsel the day before giving his evidence at this trial and looking at the Greenwood x-ray there was nothing there that would cause him concern. On cross-examination he was referred to the message from QETE to NDHQ dated April 10, 1974 which advised that a review of the Greenwood radiographs disclosed a crack and pitting corrosion. In the face of that he maintained his position that he could not today see anything on the Greenwood x-ray that would lead to any fracture or failure. He testified that the only note that he would make on the interpretation sheet at the time, had he been viewing the x-ray in 1973, was that there was possible minor corrosion. He was asked by defence counsel whether he would follow up on what he saw as possible minor corrosion and he responded that after the second read if he and the second reader were satisfied that there was something there to cause failure, then they would bring someone else in. I thought this not particularly responsive to the question. One would have thought that if the readers were looking for discontinuities and if Mr. Burke would have noted on the interpretation sheet in 1973 possible minor corrosion, then that observation would have been followed up. As it turned out, of course, we know that the corrosion was not minor, that it was fairly significant, and had to be removed by Boeing U.S.A. during the course of the 2500 hour/4 year inspection by shaving off maximum plus material from the area of corrosion.

92 Robert Risk was called to give evidence on behalf of the plaintiff. In 1973-74 he held the rank of Sergeant and was second in charge of the NDT unit at Edmonton. At the time of this occurrence he had been involved in non-destructive testing since 1963. He had received NDT training in all five methods and had attained level 2 status in all of them and had achieved a further level in both x-ray and magnetic particling. During the course of examination-in-chief Boeing's Alert Service Bulletin's A107-321 (May 25, 1973) and A107-325 (November 10, 1973) as contained in Exhibit 4 were presented to Mr. Risk, I assumed for the purpose of emphasizing that A107-321 related to inspection procedures for crack detection whereas A107-325 related to inspection procedures for detecting corrosion. Interestingly, Mr. Risk testified that he had never seen either Bulletin before. He did explain, however, that corrosion or cracks can be separate entities or closely associated and that in their inspections at the material time DND technicians would be looking for any abnormality that they thought might jeopardize serviceability of the blade. Under cross-examination Mr. Risk was asked to view the Greenwood x-ray on the x-ray viewer in court. When Mr. Risk looked at the Greenwood x-ray he saw neither corrosion nor a crack. Conclusion 10 of Dr. Laister's report was put to Mr. Risk. Dr. Laister had concluded that the discovery on the Greenwood radiograph of the crack when examined at Greenwood, could have been effected had the reader of the radiographs at that time been aware of the serious nature of corrosion on the component. In the face of this Mr. Risk maintained his position that on viewing the Greenwood x-ray he did not see any corrosion and as he put it "... certainly nothing that I would record as corrosion". It was his evidence that on viewing the Greenwood x-ray he would have reported "no rejectable indications detected" and would have passed the

blade.

93 Mr. Tasseron examined the Greenwood x-ray during the course of his evidence. He looked at it through a magnifying glass but commented that use of the magnifying glass was not specified as part of the technique 7 GX REV 1. He commented that assuming the Greenwood x-ray was a copy it was one of quite good quality. He thought it likely that it had been made from the original at Trenton after the crash investigation was completed. In his view it was of sufficient quality to see the amount of detail that a technician was normally concerned with. In his opinion the copy that was being used for the purpose of this trial would be virtually identical with the original and that a viewer would not be misled by it in comparison to the original and that the viewer would be at no disadvantage viewing the copy as opposed to viewing the original. Mr. Tasseron was asked for his opinion as to whether a reasonably competent viewer viewing the x-ray would have been able to detect a crack or anything requiring an Unsatisfactory Condition Report. He responded that what was visible on the x-ray were artifacts that were typical of artifacts seen on numerous x-rays of rotor blades of similar age. He commented that the artifacts seen on the Greenwood x-ray would repeat themselves randomly on the x-rays of other blades. He then indicated that in retrospect what was being seen on the Greenwood x-ray was early signs of corrosion. He was satisfied, however, that for routine work he did not see anything on the x-ray that would require further investigation.

94 In further discussing the quality of the Greenwood x-ray Mr. Tasseron commented that the left half of the film, that is the half in which the corrosion and crack are not located, was overexposed. In his view, the right half, which contains the anomalies and the crack, was properly exposed. It was his evidence that had he been the technician at the time he would have reshot the left side but not the right. As far as the right side was concerned he could see flaws there and so in his view the density was satisfactory and the right side was adequate for inspection purposes.

95 I had occasion to view the artifacts on the right hand side of the Greenwood x-ray with Mr. Tasseron. There were a number of artifacts surrounding the marked location of the crack and I noted at least a half dozen artifacts that were particularly noticeable as one looked at the film. It was Mr. Tasseron's evidence that notwithstanding the existence of these artifacts, he would "probably pass the film". Notwithstanding that these were, as he put it, anomalies that he would not be able to identify, he felt the anomalies were not unusual.

96 Under cross-examination Mr. Tasseron confirmed for defence counsel that the purpose of the x-ray inspection was to detect discontinuities and that discontinuities include corrosion. He confirmed that 7 GX REV 1 was capable of revealing corrosion. He was asked whether 7 GX REV 1 in the case of the Greenwood x-ray was successful in revealing corrosion at Station 169 to 174 (the Station at which the blade failed) and his response was "Yes, this film reveals corrosion". Surprisingly he then testified that he could not say whether the technician at Greenwood at the time should have seen it as corrosion. He testified that some technicians might have interpreted it as corrosion, while others might not. It was his evidence that one could only tell if the technicians who viewed this x-ray saw corrosion if the x-ray was marked with a grease pen or if the interpretation sheet indicated corrosion. The original x-ray not being available and there being no interpretation sheet, Mr. Tasseron had no way of knowing whether the technicians at Greenwood saw corrosion or not. He testified, however, that he could see it on the x-ray when he viewed it today.

97 On cross-examination, Mr. Tasseron confirmed that because of the lack of density on the left side, he would have reshot the entire x-ray with some adjustment to get better density on the left hand side, either by way of increasing the x-ray time, increasing the radiation or changing the distance and he admitted to the possibility that in so doing the quality of the right hand side of the x-ray would have been improved.

98 Mr. Tasseron made an interesting disclosure to defence counsel. Notwithstanding his evidence that he did not view the anomalies shown in the Greenwood x-ray (Exhibit 7A) to be unusual and that such anomalies would be shown in any number of the x-rays taken along the length of the subject blade, he told defence counsel that he had had occasion to view other films in Exhibit 7 which were films of the subject blade taken at Greenwood and that he had not seen in the other films a similar concentration of artifacts in any film other than Exhibit 7A. He confirmed on re-examination that he did indeed look at the other Greenwood x-rays of the spar and he saw none with a grouping similar to that as disclosed in Exhibit 7A. He went on to say that he doesn't ever recall seeing any blade x-ray with a similar grouping.

99 Dr. Laister, in preparing his report dated April 1974 for QETE, examined the Greenwood x-ray and found evidence of corrosion pitting. He explained that by x-raying the inboard portion of the blade he was able to line

up the structures of corrosion pitting and cracking with the Greenwood x-ray and he was able to detect that there was a crack showing in the Greenwood x-ray and that there was showing as well a corrosion pit that was associated with the crack. The doctor, of course, was quite satisfied that the ultimate failure of the subject blade originated from the crack site that is disclosed in the Greenwood x-ray. He explained that the crack was visible in the Greenwood x-ray because of the corrosion products existing there. Those corrosion products occupied a greater volume than the material from which they came and therefore forced the crack apart. As well, corrosion is more dense than steel and is therefore distinguished on the x-ray.

100 Dr. Laister differed from Mr. Risk in his opinion as to the quality of the Greenwood x-ray, Exhibit 7A. From what he could recall of the original which he had before him in preparing his report at the time, the copy Exhibit 7A is not of as good quality. He recalled that when he first put up the original of Exhibit 7A in 1974 he used an ordinary light box of the type that was available to us in court. The first thing that struck him at the time was a mottling which looked like pitting corrosion. The question he had at the time was whether it was real or some kind of an artifact. He checked the emulsion on the radiograph. It was satisfactory and he therefore concluded that what he was seeing on the original x-ray was evidence of corrosion. Because he was already aware that there had been a crack in the spar and knowing where to look, he looked to see whether the x-ray disclosed a crack associated with the pits. He used a ten times magnifying glass and it was "patently evident" that there was a crack indication on the x-ray at one of the corrosion pits.

101 Dr. Laister confirmed on cross-examination that he stood by the conclusions that he arrived at at the time and as disclosed in his report namely that the subject blade spar was cracked when radiographed at Greenwood prior to its return to Boeing U.S.A. for overhaul and that extensive pitting corrosion in the vicinity of the crack was disclosed on the Greenwood radiograph. It was his evidence that the corrosion was evident on the Greenwood x-ray that he reviewed in 1974 and that it remains evident on Exhibit 7A as he looked at that radiograph during the course of this trial.

102 As I understood the doctor's evidence, he does not now believe that the crack indication on the Greenwood x-ray would have been discovered by a technician because in 1973, as far as he could determine, technicians did not know of the association between corrosion pitting and cracking. He advised defence counsel that he based this assumption on what he had been told.

103 Harry Gendron, who was a Senior Radiogapher at Greenwood at the material time and who was in charge of the NDT unit there, in his evidence, acknowledged that the 7 GX REV 1 x-ray technique in place at the time had, as its purpose, to detect discontinuities and he acknowledged that while there was no definition of discontinuities in the technique, as far as he was concerned discontinuity included anything from corrosion to a crack. He understood that to be the case in 1973 and his crew understood that as well. It was Mr. Gendron's evidence that at the time of the Greenwood x-rays no Non-Destructive Testing Report was completed and that none was necessary. He was referred to the Board of Inquiry report (Tab 193, Exhibit 2 at page 82) which is a Non Destructive Testing Report on the subject blade arising out of the Edmonton x-rays. It is a "Nil" report with the result noted "No defects indicated". Mr. Gendron was unable to recall whether this form of report was in use at Greenwood at the time. He recalls that the interpretation sheet was in use and it was his general recollection that only if there was a defect was a Non-Destructive Testing Report made up.

104 When Mr. Gendron and his crew in Greenwood heard of the accident, they got out the x-rays on the subject blade to read them and to determine if they could see any defect. His best recollection today is that when he looked at the Greenwood x-rays in 1974, he could not see any crack but could see light corrosion. He recalls as well looking at the interpretation sheet where light corrosion had been noted. It was his evidence that at the time light corrosion was of no concern to the technician so that it had been simply marked down on the interpretation sheet and the matter went no further. It was his evidence that he would not have, at the time, completed an Unsatisfactory Condition Report for light corrosion. It was his evidence that "It wasn't a problem according to Boeing or whatever".

105 Mr. Gendron then changed his evidence to some extent and advised defence counsel that in fact a written report was filed with Greenwood, the report being similar to the Non Destructive Testing Report shown at page 82 of Tab 193, the Board of Inquiry Report relating to the Edmonton x-ray. If such a Non Destructive Testing Report was in fact filed at Greenwood, one can infer that it reported "no defects indicated" in as much as when Mr. Gendron was asked what Greenwood would have done in the event that the report identified a defect, his response was that it simply never happened.

106 Mr. Gendron was referred again to 7 GX REV 1 which had as its stated purpose the detection of discontinuities before they became large enough to cause failure of the blade. Initially, he had advised defence counsel that as far as he was concerned "discontinuity" included anything from corrosion to a crack. He again changed his evidence to some extent and testified that "discontinuity" would include heavy corrosion as opposed to just corrosion. He explained that at Greenwood if a discontinuity was detected on the radiograph, he would make the decision as to whether or not the discontinuity was serious enough to ground the blade. If it was not serious enough to ground the blade, then the report that was filed would simply say "No defect indicated" as was the case in the Edmonton report.

107 Mr. Gendron in his evidence confirmed that at Greenwood in 1974 some technician had identified light corrosion and had reported that in the interpretation sheet but the interpretation sheet was not sent to Summerside and the fact that light corrosion was detected on the blade was never conveyed to Summerside. Mr. Gendron testified that he did not think at the time that the Summerside pilot on whose helicopter the subject blade was in service, would want to know that it had light corrosion on it.

108 Mr. Gendron then made an interesting revelation. The procedure at Greenwood at the time was such that Greenwood kept the original x-rays, made copies of same and sent the copies to Trenton along with a copy of the interpretation sheet which, in this case, according to Mr. Gendron's evidence, would have indicated light corrosion on the blade. The strange result of this procedure, which was standard procedure at the time, was that CFB Trenton would know that there was light corrosion on the subject blade but Summerside, where the blade was in service, would not know because the interpretation sheet was not sent to Summerside. As I understood Mr. Gendron's evidence, the only report that Summerside would get would be a copy of the Non-Destructive Testing Report indicating "No defect indicated". Mr. Gendron was able to confirm that at no time subsequent to the copies being sent to Trenton, did he hear back from Trenton and he does not believe that Trenton read the x-rays or the interpretation sheet when received. Trenton's only responsibility with respect to the copies was to store them in the event the originals at Greenwood were lost.

109 It was Mr. Gendron's evidence that he cannot remember ever reviewing a Boeing Service Bulletin while at Greenwood. He never received from DND between 1970 and 1974 any information that DND was receiving from Boeing. He never received any information with respect to corrosion problems in the root box area of the spar. There were never any internal conferences or information sheets distributed by DND. There were never any advisories from DND. Mr. Gendron confirmed in his evidence that no one from Boeing or from DND ever told him not to be worried about light corrosion on the blade spar. He was asked whether anyone from DND had ever defined for him "discontinuities" under 7 GX REV 1 and his response was "just cracks". This appeared to be in direct conflict with his earlier evidence that discontinuities included corrosion and his subsequent evidence that "discontinuities" included heavy corrosion. He explained that it was just a practice at Greenwood that light corrosion was not considered a problem.

110 Finally, Mr. Gendron was asked to examine the Greenwood x-ray on the viewer. He was able to identify Exhibit 7A immediately as a copy. He looked at the film through a magnifying glass which he said was regularly used at Greenwood and was able to see several white dots on the right hand side of the film (more than ten). He then made an interesting observation to the effect that in his reading of x-rays at Greenwood, corrosion was always located on the right hand side of the film and he never reported it as a defect.

111 Stephen Ward Harrison was called by the plaintiff to give evidence. He is presently a Chief Warrant Officer stationed at Cold Lake, Alberta. He has been with Canadian Forces for some thirty three years. He first went to Greenwood in 1967. He took his NDT unit training in 1971 and worked in the NDT unit at Greenwood until 1978 in the radiograph department.

112 It was Mr. Harrison's evidence that he was the radiographer who took the Greenwood x-rays in 1973. He knew that the purpose of x-raying the blades was to look for discontinuities large enough to cause failure of the blade. (The actual purpose as set out in 7 GX REV 1 is to "detect discontinuities before they become large enough to cause failure". In my view, there is a slight but very important distinction between the purpose as set out in 7 GX REV 1 and what Mr. Harrison understood the purpose of x-raying to be.) Mr. Harrison went on to explain that in viewing the x-rays the technicians primarily were looking for cracks. He explained as well that the technicians did not use a magnifying glass as a general rule but rather used a glass only if they first found a suspected area. Mr. Harrison explained that as a matter of procedure, each radiograph had an interpretation sheet that was signed by the two readers after viewing. It was his evidence that he was one of the readers who

signed the interpretation sheet for the Greenwood radiograph. He recalls his unit receiving a message following the crash requesting that all x-ray materials be sent to either Trenton or Edmonton. Mr. Harrison, before sending out radiographs, reviewed them and he saw no defect on the radiographs nor any defect noted on the interpretation sheets.

113 Subsequently in his examination-in-chief Mr. Harrison changed his evidence and testified that he did not recall the interpretation sheets for the Greenwood x-rays nor what they said. This was after he had been asked to view the Greenwood x-ray, Exhibit 7A, in court. He noted that he last saw this x-ray approximately twenty years ago and commented immediately that it was not the original Greenwood x-ray. He noted that the density was not uniform across its entire width. He implied that the original would have been darker on the right side and as I understood his evidence, offered this as an excuse as to why at the time the readers did not see the markings on the right side of the x-ray which are apparent now. He explained that if the density was darker on the right side as he believes is was in the original, then the readers would not have seen the dots and that the density on the right side is lighter on the copy, Exhibit 7A, than it had been on the original. However in cross-examination, he criticized the quality of the right side of Exhibit 7A as not being dark enough. He explained that if it was darker, then it would be within the x-ray technique and he confirmed for defence counsel that darker was better because it helped the reader see more. This seemed to be in conflict with his evidence in chief.

114 Mr. Senderoff in his evidence testified that if the subject blade had come down to Boeing U.S.A. in the usual course with an unsatisfactory condition report indicting corrosion and accompanied by the Greenwood x-ray, Boeing would have looked at the x-ray and might have spotted the crack but, in any event, Boeing would look at the Greenwood x-ray, would probably reshoot the x-ray, and take it from there if any corrosion was found, going through the same steps with respect to that corrosion as they did having discovered it during the course of the 2500 hour/4 year inspection.

The Review Order

115 It should be noted that by message form dated September 21, 1973, DND sent out a directive to all NDT units, including Greenwood, following the crash of the helicopter in Japan on August 20, 1973. It is worthwhile to set out in its entirety the direction which is found at Tab 151, Exhibit 2.

1. DUE TO A ROTOR BLADE FAILURE IN A FOREIGN DEFENCE FORCE WE HAVE BEEN ADVISED BY BOEING VERTOL TO HAVE ALL OUR ROTOR BLADE RADIOGRAPHS RE-EXAMINED TO ENSURE THERE IS NO SIGN OF SPAR CORROSION ESPECIALLY INTERNAL CORROSION.
2. ALL NDT FACILITIES HOLDING RADIOGRAPHS OF SUBJECT ROTOR BLADES WILL EXAMINE THE ORIGINAL RADIOGRAPHS OF BLADES AND CORRELATE THIS WITH THE LATEST RADIOGRAPHS TO DETERMINE IF ANY CORROSION HAS OCCURRED
3. PARTICULAR ATTENTION IS TO BE PAID TO THE "HEEL" OF THE SPAR ON EXPOSURE ONE (1) 90 DEGREES AT STATION 54-60. HOWEVER ALL RADIOGRAPHS ARE TO BE THOROUGHLY REVIEWED.
4. ANY ROTOR BLADE SUSPECTED OF HAVING CORROSION IS TO BE REMOVED FROM FLIGHT, QUARANTINED IMMEDIATELY AND REPORTED TO THIS HQ. NIL RETURNS ARE REQUIRED.
5. EFFECTIVE IMMEDIATELY REF A, UNDER PURPOSE OF INSPECTION INSERT NEW PARAGRAPH TO READ QUOTE TO DETECT DISCONTINUITIES AND SIGNS OF BOTH INTERNAL AND EXTERNAL CORROSION BEFORE THEY BECOME LARGE ENOUGH TO CAUSE FAILURE OF THE BLADE. UNQUOTE. DELETE EXISTING PARAGRAPH

THIS IS AN INTERIM POLICY UNTIL MORE TECHNICAL INFORMATION IS AVAILABLE.

116 This directive predated Boeing Alert Service Bulletin A107-325 dated November 10, 1973 entitled "Inspection of Rotor Blade for Corrosion" which was the first Boeing Service Bulletin sent to customers relating to customer x-raying specifically for corrosion. It is to be noted that Alert Service Bulletin 107-325 directs that the blade be rejected if there is any indication of corrosion or other defects.

117 Mr. Clark in his evidence testified that he had no recollection of ever having seen the directive dated September 21, 1973. He testified as well that it would have been a monstrous job for the Canadian NDT units to examine the original radiographs of the helicopter blades and co-relate the original radiographs to the latest most current radiographs to determine whether any corrosion had occurred. He explained that there were sixteen helicopters with six blades each and forty x-rays per blade. Mr. Clark had no idea as to what was done about the directive at the time. He does not know what number of x-rays were reviewed, if any, and does not know whether the x-rays of the subject blade were reviewed. Mr. Clark did however confirm in cross-examination that the message of September 21, 1973 would be taken seriously and although the particular NDT unit would complain about the work, the work would have to be done.

118 Mr. Chapman gave essentially the same evidence as Mr. Clark. It was his evidence that he had never seen the message form dated September 21, 1973 prior to this litigation. He conceded that according to the message form, all x-rays of all helicopter blades should have been reviewed but he has never personally seen a report on a particular blade arising out of the directive. Specifically he was unable to say whether or not the directive had been complied with at Greenwood.

119 Mr. Burke in his evidence, could not remember seeing the directive dated September 21, 1973 and could not recall anyone telling him to perform such a review.

120 Mr. Risk gave essentially the same evidence. He could not recall ever receiving the directive or being directed to conduct a review of the blade x-rays. He had never heard of the directive until three days before testifying at this trial and to his knowledge the review had never been conducted at Edmonton. He felt that to conduct such a review would have played havoc with the work assignments there.

121 Mr. Tasseron did not recall seeing the message dated September 21, 1973. In his evidence he did recall that at his unit some radiographs were looked at although he does not recall being involved in the review.

122 Mr. Gendron who was in charge of the Non-Destructive Testing unit at Greenwood at the material time, testified that he was not aware that Boeing in September of 1973 advised Canadian Forces to review all blade x-rays. He does not recall receiving any such directive nor does he recall conducting any such review of the x-rays. Mr. Gendron in his evidence was of the view that the review would not have been a difficult job and if he had received a priority message such as the message dated September 21, 1973 then he and his crew would have performed the review of the x-rays.

123 Mr. Harrison who was with Mr. Gendron at Greenwood at the material time, at first indicated in his evidence that he remembered the message of September 21, 1973 directing a review of x-rays for corrosion and as far as he knew, all of the radiographs at Greenwood were in fact reviewed for corrosion. However, on cross-examination, he disclosed that he had not seen the actual message form until the day before his evidence at this trial and that he does not recall seeing the message form itself in 1973. As well, he does not recall discussing the message with Mr. Gendron and he does not recall receiving any instructions from Mr. Gendron to conduct the review. Indeed, he does not recall discussing the message with any of the other technicians. He was asked on cross-examination whether he believed that a review was conducted and he said "I would have to say yes". He then indicated that the review that he recalls was one that took place after the crash. He then testified that he could not recall when the review took place but he does recall that the review took place on only one occasion. On balance, one would have to conclude, as I do, from Mr. Harrison's evidence that whatever review may have taken place, took place after the crash. Certainly that would be consistent with the evidence of the other witnesses from Greenwood.

124 On all of the evidence, I have no difficulty concluding, as I do, that the review directive dated September 21, 1973 was never transmitted to the personnel that would be responsible for conducting such a review, namely Mr. Gendron and his crew. I have no difficulty in concluding that no such review of the Greenwood x-rays was ever carried out prior to the failure of the subject blade and the crash of the helicopter on March 19, 1974.

125 I conclude on all of the evidence that any reasonably capable and prudent x-ray technician reading the Greenwood x-ray in 1973, would have observed artifacts identifiable as corrosion. I find as a fact that corrosion of the subject spar was identified by the x-ray technicians at Greenwood when they read the Greenwood x-ray. I find as a fact that the x-ray technicians at Greenwood did not pursue that observation further and did not consider the corrosion to constitute sufficient risk to consider it a reportable defect in the spar. I find as a fact that

by the time the Greenwood x-ray was taken, the x-ray technicians at Greenwood should have been aware of the risk of corrosion and of the danger that it might be covering an underlying crack. I find as a fact that the x-ray technicians at Greenwood were not aware of that danger because they had never been so advised or instructed by their superiors. If the technicians had been properly instructed by their own people, it is likely that the readers would have been alerted by the observation of corrosion and it is likely that they either would have had a closer look at the x-ray or would have sent it on for further review by the Non-Destructive Testing Centre. Either of those things having been done, it is likely that the subject blade would ultimately have been taken out of service.

126 In my view, the crack alone, in the absence of the corrosion indicators on the x-ray at the time, would not likely have been discovered by a reasonably capable and prudent reader. However the corrosion pits were there to be seen on the x-ray and by that point in time the DND technicians should have been made aware of the danger of corrosion and the risk that a crack might be underlying the corrosion.

127 It is clear on the evidence that at the time that the Greenwood x-ray was taken the technicians had not been properly alerted and instructed as to the significance of corrosion on the blade spar. In my view, the plaintiff must be held accountable for what I see to be the negligence of the "upper echelon" in failing to bring home to the men on the floor who were actually conducting the reading of the x-rays, the significance of corrosion showing up on the x-rays. To the extent that it failed to do so, the plaintiff has contributed to its own loss.

128 On the evidence, even more was known about the significance of spar corrosion by September 21, 1973 following the crash of the helicopter in Japan. If the message form dated September 21, 1973 had been given to the x-ray technicians at Greenwood, had they been directed to conduct the review referred to therein, had the review been conducted and had the technicians followed Direction No. 4, namely

> ANY ROTOR BLADE SUSPECTED OF HAVING CORROSION IS TO BE REMOVED FROM FLIGHT, QUARANTINED IMMEDIATELY AND REPORTED TO THIS HQ. NIL RETURNS ARE REQUIRED.

it is likely that the subject blade would have been taken out of service at that time. I find that for reasons unknown no such review was ever undertaken at the NDT unit at Greenwood. In the face of the information that the plaintiff had from Boeing as of September 21, 1973 and in the face of Boeing Alert Service Bulletin 107-325 dated November 10, 1973, the plaintiff was negligent in failing to have the review conducted and contributed to its own loss as a result thereof.

2500 HOUR/4 YEAR INSPECTION

129 During the course of the "relifing" or 2500 hour/4 year inspection at the plant, Boeing U.S.A., quite by accident, discovered the corrosion which was evident in the Greenwood x-ray. Because of damage caused to the de-icing blanket by Boeing U.S.A. workers, the de-icing blanket had to be removed from the spar and upon removal, the corrosion was observed. All of the Boeing documentation relating to the 2500 hour/4 year inspection and reworking while the subject blade was in Boeing U.S.A.'s plant is contained at Tab 136, Exhibit 2, which is comprised of some 129 pages. It is essentially a history of the subject blade during the entire time that it was at the Boeing U.S.A. plant for relifing.

130 The Boeing U.S.A. employee, Mr. Snyder, in his evidence described the Boeing U.S.A. plants as they existed in 1973 and as well described generally the passage of a blade through the plants and the manner in which repair and overhaul evaluation reports were created. Generally an inspector would document any defect on the Repair & Overhaul Evaluation Report (R. & O.). Mr. Snyder as Senior Manager, Product Quality Control, would review the R. & O. and determine if Boeing U.S.A. was authorized to do any work with respect to the defect. To do this Mr. Snyder would contact the Overhaul Group in the administration building and ask that group to determine whether Boeing had authority. The Overhaul Group would speak to the customer, obtain authorization and convey that authorization to Mr. Snyder. Mr. Snyder would then sign off the R. & O. in the box headed Vertol Quality Control and send the R. & O. onto Boeing Engineering to determine the rework required to repair the defect. Engineering would make its entry under the heading Rework Required, sign off the R. & O. and send it back to Mr. Snyder. Mr. Snyder would then send the R. & O. to the Customer Quality Assurance Representative. The Customer Quality Assurance Representative would sign off and the R. & O. would go to Tool and Production Planning for the preparation of planning papers to effect the rework required.

131 Mr. Snyder then dealt specifically with the Repair and Overhaul Evaluation Report relating to the subject corrosion that was evident in the Greenwood x-ray. That report is found at page 16 of Tab 136. The Boeing inspector in this case was Elmer Lang with four years experience on the floor. Under the heading Discrepancy Listed he noted the following:

> After removing of de-icing blanket an area of spar has corrosion on O/D bottom side located 4 1/2 inches from outboard edge of box number 9 and 2 inches from leading edge of spar.

This R. & O. was then sent on to Boeing Engineering who described the rework required as follows:

> Rework corrosion per standard No. 35, O8-4840525-(Ch 46-Standard Repair Manual)

The engineer then signed off after which Mr. Snyder signed off. The Customer Quality Assurance Representative, Mr. Hess, then signed off and the R. & O. was sent to Tool and Production Planning to prepare a planning sheet for the remedial work. After the tool and production planning person, a Mr. Crawford, prepared the planning sheet at page 19, he then signed off.

132 The same procedure was followed with respect to the R. & O. at page 17 of Tab 136. After the reworking of the corrosion, the inspector noted a low wall thickness in the area where the corrosion had been removed. It is noted in the R. & O. that the wall is .045 in thickness whereas the minimum wall thickness according to blue print is .0475. This discrepancy as listed in the R. & O. was sent to Boeing Engineering for disposition. Boeing Engineering decided that the low wall was "acceptable as is" and indicated that in the column REWORK REQUIRED. The Customer Quality Assurance Representative, Mr. Hess, then decided that he wanted the Customer Engineer to have a look at the disposition. The R. & O. was sent on to the Customer Engineer Bowes who signed off. Mr. Hess then signed off. The two Tool and Production Planning persons then made a note that no planning action was required and signed off.

133 Mr. Snyder explained that the planning page for the work that was required for the removal of the corrosion is at page 19 of Tab 136 and was made up by the planning person from Interim Standard Repair No. 35. Mr. Snyder explained that the planner took out of Interim Standard No. 35 only the specific steps required to remove corrosion. The planning page reads in part as follows:

> 8. Remove all evidence of corrosion. Blending to ratio 200/1
> 15. Flush grit blast bare steel area (S) per D8-0097
> 20. Brush zinc plate bare steel area (S) per 107-601 manual.

134 Mr. Snyder in his evidence confirmed that after the subject corrosion had been removed the reworked area was not subjected to a magnetic particle inspection nor was it subjected to any type of non-destructive testing to determine whether there might be a crack underlying the area of corrosion. He explained that the 2500 hour/4 year program required only that the spar root end and the root end socket be magnetic particled. He explained that it was not Boeing's practice to conduct a localized magnetic particle inspection on the blade. It was his evidence that it was not part of the process and it was not something that was required. He took the position that, in any event, magnetic particling could not be done on a localized basis without removal of all of the boxes. He explained that magnetic particling involved magnetizing the area of the spar to be tested and applying to the spar an oil base solution containing metal particles. His concern was that such a testing would have contaminated the bond surface and the rubber seals on the ends of the boxes and would permeate into the boxes. His further concern was that this magnetic particling would have to be done in the "dirty room". There would be difficulty removing all of the oil base and metal particles and eventually contamination would be brought into the "clean room" where the boxes were to be bonded to the spar.

135 I must say that this evidence seemed rather far fetched in view of the evidence given by Mr. Chapman with respect to the ease with which the reworked area could have been tested by way of magnetic particling had Boeing U.S.A. chosen to do so.

136 For the purpose of this trial, Mr. Chapman conducted the following experiment. He took a piece of 4340 steel (the same steel as used in the subject spar and of the same thickness as the subject spar) and by applying repeated stress to this piece of steel, created a stress crack in the steel which was 163/1000 of an inch long on one side and 167/1000 of an inch long on the other. This manufactured crack was within 4 to 5/1000 of an inch the size of the crack in the subject spar before failure. Mr. Chapman then ground 25/1000 of an inch off

the top and off the bottom of the steel plate at the crack site and was left then with a thickness of plate at the crack site of 50/1000 of an inch. This grinding would have been equivalent to the reworking by Boeing U.S.A. and Mr. Chapman was then left with a piece of steel that was equivalent to the area of the subject spar that remained after the reworking by Boeing U.S.A. The piece of test steel was entered as Exhibit 42 in these proceedings.

137 A very close look at the test piece does not permit visual detection of the crack. In other words, the crack cannot be seen after the grinding. As an aside, Mr. Chapman testified that if he had been the technician that had ground the corrosion off the spar he would not have relied on visual inspection to determine whether a crack was underlying the corrosion nor indeed would he rely on visual inspection to determine whether or not all of the corrosion had been removed by the reworking. It was his evidence that in 1973 any reasonable technician would ensure that an NDT technique, either magnetic particle or ultrasonic, would be performed on the piece after removal of corrosion to ensure that the corrosion was gone and that the area was sound. It was his further evidence that if the remaining wall thickness of the material was at or below minimum, then the technician in 1973 would make doubly sure to do such non-destructive testing after rework.

138 In any event, in court Mr. Chapman then conducted a magnetic particle inspection of the test piece. The application of the magnetic particle inspection was extremely easy. Mr. Chapman put a magnet on the test piece which had the effect of polarizing the crack. He then sprayed ferrous particles on to the surface of the test piece and the crack was very clearly defined by the ferrous particles under black light by reason of the fact that the ferrous particles are attracted to and collect on either side and at each end of the crack. The whole process took thirty seconds and might be described as almost magical. Under black light there was the crack where it could not be seen before. Mr. Chapman then cleaned the area with solvent and removed the magnetism on the piece with alternating current. The total time for the whole exercise was less than five minutes and the materials required were not worth more than $5.00 or $10.00. It was Mr. Chapman's evidence that there would have been no difficulty in the Boeing U.S.A. plant, using the magnetic particling technique, to magnetize the small reworked area of the 25 foot blade, to apply the ferrous material, to view the area in black light and to clean up the area subsequent to the testing without contaminating the blade in any way. It was Mr. Chapman's evidence that had that testing been done the .163 inch through crack that existed at the time that the blade was on the Boeing U.S.A. plant floor, would have been detected.

139 It was Mr. Snyder's evidence-in-chief that he knew of no instances when magnetic particling had been applied locally to a spar without tearing it down completely, that is without removing all of the boxes, other than when it was applied as required under the 2500 hour/4 year program to the spar root end and root end socket. Mr. Snyder stipulated a number of reasons why the localized area of rework could not have been tested by way of magnetic particling. He talked about leakage into the adjacent box but was able to confirm that in fact box 9 which was in the area of the subject corrosion, was one of the boxes that was removed during the inspection. As well he said there were engineering concerns about contamination of the spar surface from the oil and metal particle solution. He then went on to say that it was his understanding that he could not get the proper electrical charge into the localized area in order to create the magnetic field that is required for magnetic particle inspection.

140 Mr. Snyder then made a rather startling revelation. He was shown the small hand held horseshoe magnet filed as Exhibit 86 which Mr. Chapman had used to create the magnetic field on Exhibit 42, the small piece of steel with the manufactured crack in it. He testified that he had never seen such an instrument before. He then testified that he had never seen before the small hand held aerosol can of oil base and ferrous particles that had been used by Mr. Chapman to demonstrate the crack in Exhibit 42. He explained that at the Boeing plant, in the magnetic particling area, the worker used a hose to apply the metal particle solution. In the face of these admissions Mr. Snyder's concerns about the application of a localized magnetic particling test became clear. In my view when he was talking about magnetic particling he was talking about it in terms of the set up that Boeing U.S.A. had in its blade shop. Mr. Snyder had previously explained that the shop induced a magnetic field around the entire spar by placing a rod through its entire length and then winding the coil around the entire spar. He described how then the solution would be hosed on and eventually cleaned off in the de-greasing vat. Essentially, his evidence was that as far as his shop was concerned, they were simply not set up to do a localized magnetic particle inspection such as that demonstrated in the court room by Mr. Chapman.

141 With respect to clean up after a localized magnetic particling test, Mr. Snyder confirmed that from time to time acetone was used by Boeing to clean. Plaintiff's counsel suggested to Mr. Snyder that had a localized

magnetic particling test been conducted, then acetone could have been used to clean the localized area before taking the blade into the clean area of the plant. Mr. Snyder responded that even with an acetone cleaning he would be concerned because some of the oil could be left even with the cleaning and that it might weep out when heat is applied during the box bonding process and interfere with the bonding. In my view, considering the extensive cleaning process that must be implemented to replace a de-icing blanket or to replace an existing box which involves removing all of the adhesives, Mr. Snyder's concerns about clean up after a localized magnetic particling testing were not realistic.

142 As previous indicated, Mr. Snyder did not know about, nor had he been told by his employer about the Swedish crash in 1968 or the Japanese crash in 1973 where the blade failure was caused by a crack associated with corrosion. He did not know that there could be a crack existing under corrosion. He was never told that by his employer. He was never told by his employer that cracks could develop from corrosion. He did not know about nor had he been told by his employer about the November 1972 presentation by his employer to Canadian Forces with respect to corrosion and the risk of corrosion. Certainly the powers to be at Boeing knew of the danger of corrosion and the possibility of cracks underlying the corrosion but they failed to so instruct their people on the plant floor. It is likely that if Mr. Snyder had known what his employers knew, he would have been inclined to subject the reworked area to some form of non-destructive testing whether or not it was strictly required by the contract.

THE CONTRACT

143 Boeing Rotor Blade Inspection and Repair Manual 107-601 (Tab 8, Exhibit 2), which was in place at the time that the 2500 hour/4 year inspection and reworking took place at the Boeing U.S.A. plant, in my view, notwithstanding the position taken by Boeing, clearly calls for the inspection by way of magnetic particling of all areas of the spar reworked during the course of the 2500 hour/4 year inspection. Without going through the entire manual, paragraph 3 (c)(2)(f) thereof at page 40 reads as follows:

> (f) Inspect the following areas of the spar, using the magnetic particle inspection method, spec MIL-I-6868 (see figures 5 and 6 for criteria). (Type 1 inspection only):
>
> 3. Any and all reworked areas.

144 The defendants argue that even if their Rotor Blade Inspection and Repair Manual 107-601 calls for a magnetic particle inspection of the area of the subject spar from which the corrosion was removed, that manual is not the service bulletin applicable to the 2500 hour/4 year inspection and rework. In one of the three letters constituting the 2500 hour/4 year contract between the plaintiff and the defendants, namely the letter dated December 8, 1971 to Boeing of Canada, the Chief of Defence staff asked for advice as to whether or not a service bulletin had or would be issued to detail the requirements of the relife inspection. The answer from Boeing by way of letter dated March 3, 1972 was that a service bulletin was not required and would not be issued since instructions were already set forth in the 107-6 Maintenance Schedule. However, if one looks at Boeing Maintenance Schedule 107-6 which is Exhibit 25, the first paragraph under the heading 1. General reads in part as follows:

> This manual contains complete requirements for maintenance inspections and component replacement. It does not contain remedial instructions for defective conditions located during inspection ...

On the other hand Boeing Rotor Blade Inspection and Repair Manual 107-601 which is the very first reference in Appendix A to Boeing's letter of March 3, 1972 setting out the purpose and work description of the 2500 hour/4 year inspection, stipulates in the Forward as follows:

> This manual contains instructions for the inspection and repair of the rotor blade used in high utilization rate (commercial) operations.

145 The conclusion that the directions in Boeing manual 107-601 were intended to apply to work being performed as a result of the 2500 hour/4 year inspection is supported by the fact that there are dozens of Boeing documents relating to blade repairs that refer to Boeing manual 107-601.

146 At Tab 35, Exhibit 2, there is a Boeing Service Bulletin dated December 30, 1969. It is noted on page 1

that this particular bulletin revises and supersedes Boeing Service Bulletin 107-269 dated January 10, 1969 to provide an alternate method to verify crack indications in rotor blade spars. At page 9 of this new Service Bulletin under the heading References there is a reference to Boeing Rotor Blade Inspection and Repair Manual 107-601. As well, at page 4 of the new Service Bulletin there is again reference to 107-601.

147 At Tab 135, Exhibit 2, is Boeing Alert Service Bulletin A107-321 dated May 25, 1973 which contains a warning as follows:

> Failure to comply with the instructions in this Service Bulletin could result in an undetected failure of a rotor blade spar and potential catastrophic failure.

In paragraph 7. thereof under the heading References there is listed:

> 107-601 Rotor Blade Inspection and Repair Manual

148 At page 5 of this bulletin under the heading of "Inspection of Zinc Plating", the following is noted:

> (5) If the steel spar is exposed, replace the zinc plating. Refer to Rotor Blade Inspection and Repair Manual 107-601.

149 At Tab 136A, Exhibit 2, is a BOEING QUALITY ASSURANCE OPERATING INSTRUCTION dated September 1, 1970, its subject being:

> Receiving, Evaluation, Repair Of Rotor Blades Returned From Service.

It was Mr. Snyder's evidence that he had a hand in the preparation of this document and that it was meant to provide instructions to Snyder's inspectors with respect to any work being done on the blades.

150 Paragraph I.A.3. of the document provides in part as follows:

> 3. Inspection of Repairs
>
> a. Inspect, per planning orders, reworked areas.

Paragraph II of the same document is entitled References and one of the references listed is 107-601.

151 Indeed, there is reference to 107-601 in the planning paper (page 19 of Tab 136, Exhibit 2) prepared for the purpose of giving instructions for the removal of the subject corrosion. Item 20 of the planning paper provides as follows:

> Brush zinc plate bare steel area (s) per 107-601 manual.

152 There are many other references to 107-601 that could be listed. In my view the contract entered into between the parties imposed a contractual obligation on Boeing to inspect by way of magnetic particling the reworked area and its failure to do so constituted a breach of the contract. I find as a fact on all of the evidence that had the reworked area been inspected by way of magnetic particling after the rework, it is likely that the crack, which eventually caused the failure of the rotor blade and the crash of the helicopter, would have been detected.

153 I must say in arriving at the conclusion that there was a contractual obligation on the part of Boeing to apply the provisions of their Inspection and Repair Manual 107-601 to the rework, I have rejected Mr. Senderoff's explanations as to why the provisions of the manual should not apply and particularly his explanation that the purpose of 107-601 was not to be used as a field manual but rather was intended to be used by Boeing customers who wish to set up their own repair facility. The Foreword to the manual specifically states that it is intended to be used in conjunction with airframe manuals as designated, including 107-6. The Foreword further reads in part as follows:

> The code "60-10-1" is assigned to the pages within this manual, however, the only significance is to establish continuity between this publication and the 107-II series of service manuals.

As well as page 3 of 107-601 under the heading Introduction, the purpose of the manual is set out and reads

as follows:

> This manual provides information on special, sampling, and preventive inspections. Repairs or dispositions and the testing requirements subsequent to the inspection and rework of the rotor blade received for timed scheduled inspections or service incurred rework are included.

Following the stated purpose there is a specific note in the manual which reads in part as follows:

> The operators approval for all necessary rework or disposition instructions are required prior to any rework or repair.

Obviously, that constitutes an instruction to the Boeing technicians on the floor and is not an instruction to a Boeing customer setting up or operating his own facility. Mr. Snyder in his evidence testified that he was familiar with Boeing manual 107-601 and conceded that it was of some use in the Boeing U.S.A. plant. The tool and production people had a copy of it in order to write planning papers and there was a copy on the shop floor available to the mechanics and inspectors. In the face of Mr. Senderoff's evidence in chief that Boeing made very little use of 107-601 because there were shop cards and planning papers available to cover all the required work in the Boeing plant, Mr. Senderoff made the following admissions on cross-examination:

Question: Well isn't it true sir that the shop cards that you have referred to many times, the shop cards, sir they were designed to fulfill the intent of the 107-601 weren't they?

Answer: Oh absolutely.

Question: Absolutely. O.K. So in fact they were to be drawn, in principle, off the 107-601 rotor blade manual in principle; do you agree with that?

Answer: I wouldn't say it was drawn from. I would say that our processes would certainly be equal or better than the processes that are included in the 601 manual.

Question: And they were to fulfill the spirit of the 107-601 rotor blade repair manual, is that fair?

Answer: Yes I would say they fulfilled the spirit, yes.

Question: All right and so when Col. Dyack accepted the agreement in March of 1972 that appears in P-75 he would have, when he was noting, approving, or accepting the calling up and reference of the 107-601 manual, have expected that at least the minimum requirements of that manual would be complied with; would you agree with that?

Answer: The minimum requirements of that manual as applicable to the tasks that were being called out would have been complied with.

Question: O.K. in that sense the 107-601 manual was applicable to this job; is that fair?

Answer: Yes.

Question: You will agree with me that in substance the agreement was at least the requirement of the 107-601 would be complied with, or better; is that fair?

Answer: Yes.

Question: And I am just suggesting to you it was up to Boeing to make sure that its shop cards -- I don't care when they were made -- that they lived up to the intent of that rotor blade repair manual as it was referenced in this agreement; that's fair isn't it?

Answer: Oh I agree with that.

MAGNETIC PERTURBATION

154 Schedule A to Boeing's letter dated March 3, 1972 to the Chief of Defence staff provides that as part of the 2500 hour/4 year inspection the rotor blade was to undergo a magnetic perturbation inspection. The evidence disclosed that prior to the rework of the corrosion, such an inspection was conducted. The subject blade passed the magnetic perturbation inspection without disclosing either the corrosion or the underlying crack. Boeing manual 107-601 at page 9 thereof under the heading Inspection provided as follows:

> (6) Table 6. Final Inspection Requirements is applicable to all rotor blades subsequent to any rework or repair and is intended for use as a check to ensure that those details which might be overlooked inadvertently are inspected.

Table 6 at page 100 of 107-601 titled Final Inspection Requirements provides as follows:

Area	Inspection

Spar	Cracks, nicks, scratches or other damage using magnetic-perturbation inspection system, part AO2GS005-1 use criteria given in figures 6 and 7.

155 Having regard to those provisions, arguably Boeing U.S.A. was required under the contract to inspect the reworked area by way of magnetic perturbation following rework. This was not done. However insofar as the first magnetic perturbation inspection failed to disclose either the corrosion or the underlying crack, I am unable to conclude that a final magnetic perturbation inspection following rework would likely have disclosed the crack. In the result, if there was a breach of contract on the part of Boeing U.S.A. in this regard, it cannot be said that it contributed in any way to the ultimate failure of the rotor blade.

COMMON LAW DUTY OF CARE

156 Contractual obligations aside, I am of the view in the circumstances of this case, Boeing owed to the plaintiff the common law duty of care and breached that duty.

157 At the time that the rework was being done on the subject blade at the Boeing U.S.A. plant, Boeing was fully aware that corrosion could be an indication of an underlying crack. The crash of the helicopter in Japan in August of 1973 was to the knowledge of Boeing, caused by the failure of a rotor spar which in turn was caused by a corrosion related crack. Following that crash, Boeing alerted the plaintiff which resulted in the plaintiff in turn alerting the NDT units by message dated September 21, 1973 to re-examine blade radiographs and to remove from flight any rotor blades suspected of having corrosion.

158 During the course of cross-examination Mr. Senderoff conceded that by March of 1973 when the subject blade went to Boeing U.S.A. for the 2500 hour/4 year inspection, Boeing knew that magnetic perturbation would not detect fatigue cracks as Boeing had represented in its tandem note titled Magnetic Perturbation dated March 26, 1969 (Tab 18, Exhibit 2) to its customers which note read in part as follows:

> Magnetic Perturbation Inspection (Mag Pert) is the detection of distorted (perturbed) magnetic lines of flux on the surface of magnetized steel. The perturbations were caused by non-magnetic inclusions, voids, chemical segregations, cracks and lapse which change the magnetic permeability of the steel. (underlining mine)

159 Notwithstanding that representation, Boeing came to know and knew during the course of the relifing of the subject blade, that magnetic perturbation inspection would not disclose cracks. This inability was never disclosed to Canadian forces. Boeing's knowledge that magnetic perturbation inspection was incapable of detecting a crack in the spar (as was proven during the course of the 2500 hour/4 year inspection) was all the more reason why Boeing should have, as a reasonably prudent repairman, taken the time to subject the reworked area of the spar where the corrosion had been removed to some other form of non-destructive testing such as magnetic particling.

160 All of the plaintiff's witnesses were consistent in their view that some form of non-destructive testing should have been applied to the reworked area of the spar after the corrosion had been removed. Charles Chapman who retired from the Forces in 1985 and from that time to the present has been the senior non-destructive testing specialist at the National Research Council is familiar with corrosion. He explained that when corrosion is sanded out of a rotor blade, as it was in this case, one cannot visually see if the corrosion has been removed completely but can see if the pit has been removed. It was his evidence that one could not visually detect a small crack under a blended pit. He explained that when, in his work, he had to remove corrosion he always used, after removal, some type of non-destructive testing to make sure the defect was gone and the piece was sound.

161 Mr. Risk was of the view that after removal of corrosion from a blade spar there must be further NDT testing such as magnetic particling to make sure the entire indication has been removed. It was his evidence that the industry standard in 1973 with respect to repairs that after repair it was mandatory to follow up with an inspection to ensure absolute serviceability of the piece and that after removal of corrosion a visual inspection was not sufficient.

162 Mr. John Tasseron ran the Forces NDT facility in Germany with a crew of nine from 1976 to 1980. Since

1990 he has been employed by Transport Canada as a Civil Aviation Maintenance Inspector. Mr. Tasseron shared Mr. Chapman's view as to the required non-destructive testing of the reworked area by way of magnetic particle inspection to ensure that there is no crack underlying the area of corrosion.

163 Dr. Romilly in his evidence testified that having noted corrosion and having removed the corrosion in the manner in which it did Boeing should have wanted to satisfy itself of the structural integrity of the remaining wall. A visual technique would not have been sufficient for this purpose and the doctor was of the view that the most likely test to be applied would be magnetic particling to determine whether there was any surface or subsurface defect remaining. As well, he was of the view that ultrasonic testing could have been used for that purpose. In his view there was a high probability that the corrosion crack would have been detected by magnetic particling inspection.

164 Dr. Laister was of the view that having completed the reworking, Boeing would have been able to visually determine if all surface corrosion had been removed but would not have been able to determine in that fashion whether any through corrosion existed. It was Dr. Laister's view that for that purpose magnetic particling would have been the obvious choice.

165 In my view, in all of the circumstances of this case Boeing U.S.A. had a common law duty to the plaintiff to apply non-destructive testing to the reworked area. Magnetic particling would have been one obvious choice and in my view, as I have indicated before, it is likely that the subject crack would have been detected had non-destructive testing been applied after rework.

166 As well, having regard to Mr. Snyder's evidence, in my view, Boeing U.S.A. was negligent in failing to properly instruct its people on the plant floor as to the danger that a crack might be associated with corrosion and in failing to provide to their technicians appropriate equipment to conduct a localized non-destructive test following rework. It is almost incredible to think that in all of the circumstances of this case having regard to what Boeing U.S.A. knew about the problems associated with corrosion and associated cracks, that this information was never passed on to Bruce Snyder, their Senior Manager, Product Quality Control. His job was to supervise inspections of rotor blades and he did not know nor had he been told about either the Swedish crash in 1968 or the Japanese crash in 1973. He did not know that there could be a crack under existing corrosion. He was never told this by his employer. He was never told by his employer that cracks could develop from corrosion. He did not know nor had he been told by his employer about the November 1972 presentation by his employer to Canadian Forces with respect to corrosion and the risk of corrosion. Mr. Snyder struck me as the kind of man who, had he been armed with that kind of information, would not have been satisfied to leave the reworked area of the spar go untested.

167 In the result I find that there were breaches of contract and breaches of the common law duty to take reasonable care committed by the defendants which breaches contributed to the ultimate failure of the subject rotor blade in flight.

QUALITY ASSURANCE

168 With respect to Boeing's contractual liability, defence argues that Boeing was reasonably entitled to believe, in all of the circumstances, that its performance of the work pursuant to the 2500 hour/4 year inspection which took place under, as defence describes it "the watchful eyes" of the plaintiff's quality assurance representative at the Boeing U.S.A. plant and with his express approbation, had been accepted. Defence counsel points me to Irving Oil Limited v. Incan Ships Limited (1979), 26 N.B.R.(2d) 512 (NBSC) wherein it is said:

> if a person so conducts himself that a reasonable man could believe that he was assenting to the terms proposed by the other party, and that other party upon that belief enters into (or the defendants would say, continues) a contract with him, the man thus conducting himself would be equally bound as if he intended to agree to the other parties terms, notwithstanding his real intention.

169 In this particular case it is of interest to note that while the plaintiff's quality assurance representative on the Boeing U.S.A. plant floor did "sign off" the R. & O. which stipulated the discrepancy and the rework required, he would, according to the evidence of Mr. Snyder, have done so prior to the planning orders prepared by Tool and Production Planning describing the actual work to be done. Mr. Snyder acknowledged that it was not the practice of the customer's quality assurance representative to "sign off" or stamp the planning order it-

self and if one looks at the planning order relating to the subject rework (page 19, Tab 136, Exhibit 2) one will note that under the heading ACCEPTANCE there is a box provided for the stamp or signature of the plaintiff's quality assurance representative but the box is empty. In the circumstances of this case it cannot be argued that the plaintiff's quality assurance representative "approved" the planning order that failed to require non-destructive testing of the reworked area.

170 In any event, the contract between the parties was such that the involvement of the plaintiff's quality assurance representative on the plant floor would not excuse Boeing from poor workmanship or failure to perform the contracted job properly. The specific contract in force between the plaintiff and Boeing Canada at the material time was that dated May 18, 1973 intended to cover the period from April 1, 1973 to March 31, 1974. It is located at Tab 133, Exhibit 2. Paragraph 11 of the service contract provides as follows:

> 11. The contractor's system of quality control for the work described herein shall be in accordance with specification DND 1015 dated October 1965.

Article 3.5.5.4 of specification DND 1015 (found at Tab 10 of Exhibit 6) provides as follows:

> The departmental representative may require the application of government quality assurance at subcontractor's plants to ensure that materiel conforms to requirements. Any assurance of quality provided by the government does not alter the prime contractor's responsibility to provide acceptable materiel nor shall it preclude the subsequent rejection of materiel. The government quality assurance provided shall not be used by contractors as evidence of effective control by suppliers.

171 That provision is, in my view, a complete answer to the defendants' argument with respect to quality assurance and in my view the defendants cannot find any relief from liability in the fact that the plaintiff's quality assurance representative was involved in the inspection and rework process at the Boeing U.S.A. plant.

THE RELATIONSHIP BETWEEN THE PARTIES

172 The defendants argue that in determining whether or not they are liable to the plaintiff for damages, consideration must be given to the relationship that existed between the parties. It is clear on the evidence that the parties enjoyed a co-operative relationship. While the defendants were to do only that work authorized by the plaintiff, one would expect that to be the case in any commercial relationship. For example, paragraph 6 of the service contract dated May 18, 1973 reads in part as follows:

> The contractor shall repair only those items for which he has received authorization.

However, it is abundantly clear on the evidence that the plaintiff relied on the defendants' recommendations as to what additional work had to be done and provided the necessary authority when requested to do so. Indeed, the particular 2500 hour/4 year inspection involved in this action cost the plaintiff far in excess of the "not to exceed" cost of $6500 U.S. The final cost to the plaintiff was $10,439 U.S. the excess cost having been readily authorized by DND.

173 If it can be argued that the relatively simple task of performing a localized non-destructive testing to the reworked area was an "extra" to the contract, and in my view it cannot be, then it is clear on the evidence that the final testing would have been authorized by the plaintiff. Accordingly, I see nothing in the relationship between the parties, nor in the plaintiff's general approach to have only authorized work performed by the defendants, that provides any relief to the defendants in terms of their liability in this case.

ISIS

174 As a result of Boeing's experience with rotor blades failing without warning, Boeing in 1969 embarked on a program to determine what might be done by way of design to minimize such failures. Mr. Senderoff as Unit Chief of Systems Safety, was involved in a special group to undertake the program. As a result Boeing developed an integral spar inspection system (ISIS) to prevent unheralded spar failure in flight. The system involved creating a vacuum in the blade spar. When the vacuum was broken by reason of a crack in the spar a pop up indicator made that fact known to the operator.

175 On November 20, 1972 Boeing made a presentation to DND following the crash of a helicopter on Octo-

ber 10, 1972 which was the sixth failure of a rotor blade spar resulting in a serious or fatal accident. Boeing announced in the presentation that:

> There is now available an integral spar inspection system (ISIS) that will prevent such accidents.

and further

> Accordingly, the Boeing Company has recommended the accelerated incorporation of ISIS.

176 The presentation at Tab 89, Exhibit 2 is dated November 10, 1972 and it appears to have been received by DND on November 20, 1972. Mr. Senderoff was able to confirm that as of the date on the presentation, namely November 10, 1972, ISIS was in production for the United States Military but no other customers such as Sweden or Canada were picking ISIS up at that time. Boeing of Canada Limited made a formal proposal to the Canadian Forces by letter dated November 20, 1972. Tab 96, Exhibit 2 to Captain W.R. Newton. The proposal was for 115 rotor blades at a cost in excess of $8,000 per blade representing an investment by Canadian Forces of over $1,000,000. The proposal points out that the lead time for the ISIS kits was fifty one weeks after receipt of order. As well, the fitting of the kits had to be done in the Boeing U.S.A. plant which would add an additional three months to the time required to do the retrofits. Mr. Clark was asked to explain what Canadian Forces did in the face of this proposal. He explained that Captain Newton could not commit to Boeing without homework being done, inhouse approvals being obtained and budgeting having been obtained. Mr. Senderoff in his evidence had cited another customer, Columbia Helicopters, as having ordered ISIS in a timely fashion in May of 1973 and one may infer that had Canadian Forces ordered it at the same time then installation would not, according to the anticipated lead times set out in the proposal, have started until August of 1974.

177 Warren Stratton, an employee of Boeing U.S.A., gave evidence with respect to ISIS. He began his employment with Boeing U.S.A. in 1958 and in 1971 became the Chief Engineer of rotor blade design. While with Boeing he was involved with the ISIS program and as a professional engineer was involved in the various presentations to the Canadian Forces. Prior to the formal presentation dated November 10, 1972 and the formal proposal for installation dated November 20, 1972, Mr. Stratton had shared ISIS data with the Canadian technical people as it developed. It was his observation that the Canadian technical people seemed very supportive of ISIS. There were, however, several issues with respect to logistics and costs that were raised by the Canadians including the availability of funds and the interchangeability of the blades. Mr. Stratton testified that if at the end of the presentation of November of 1972, Canadian Forces had asked Boeing to prepare a program to implement ISIS, Boeing would have taken every step it could to implement the program as quickly as possible.

178 The presentation by Boeing, November 10, 1972, recommends that Canadian Forces initiate a program for installation of ISIS kits as soon as possible. In this respect, Mr. Clark explained that it would normally take three months to get authorization for a purchase order. There were new blades on order by Canadian Forces at that time and Mr. Clark sought and obtained authority to amend those purchase orders to provide that the new blades be equipped with ISIS. Kits were eventually ordered for all of the air force crafts and four of the army crafts. Kits were not ordered for all of the army crafts at that time because there were plans in place to possibly acquire new Chinook helicopters for the army.

179 Mr. Clark was of the view that ISIS could not have been installed on the subject rotor blade by March of 1974 when it failed and the helicopter crashed. It was Mr. Clark's evidence that it was a possibility that ISIS could have been installed on the subject rotor blade had that particular blade been picked as number one for installation but such was not the case. Mr. Clark denied that Canadian Armed Forces in any way dragged its feet in terms of the implementation of ISIS. It was his evidence that the Forces simply had priorities to follow and decided to equip the Air Force helicopters first.

180 In his evidence Mr. Clark explained that the Canadian Armed Forces began to assign Canadian Forces serial numbers to the ISIS blades when they received the thirty new blades and planned to eventually retrofit all of the Air Force blades with ISIS kits. The decision had been made to make all blades into which the ISIS kit was being installed, Air Force blades with de-icing blankets so that when the army helicopters were phased out, as was then being planned, their blades could be used as spare blades for the Air Force helicopters.

181 Mr. Clark went on to explain that when the subject rotor blade arrived back in Canada in December of 1973 after its 2500 hour/4 year inspection, it had the lowest status in terms of installation of ISIS because it was the latest relife blade. Accordingly, the other blades (there were some twenty helicopters in all) would have

had priority for ISIS installation.

182 There were several pieces of correspondence put in evidence that indicated quite clearly that Canadian Forces were prepared to accept the recommendation of Boeing and wanted ISIS installed as soon as possible. For example, the memorandum from Colonel W.E. Castellano dated January 8, 1973 closes with the following:

> 7. In summary, DAE agrees with the Boeing Vertol analysis and considers it mandatory that an integral inspection system be incorporated as soon as possible.

183 It should be noted that following the crash Boeing sent a telex to the Canadian Armed Forces dated March 28, 1974 giving a firm recommendation that the helicopters equipped with non ISIS blades be immediately grounded. Boeing had made no such recommendation prior to the crash. It had made recommendations as to periodicity of x-rays in the absence of ISIS and Canadian Forces were abiding by those recommendations.

184 At Tab 192, Exhibit 2 there are DND Minute Sheets giving statistics on ISIS blades as of March 29, 1974. It appears that on that date DND had twenty three ISIS blades in the system. As well, DND had two new ISIS blades coming with delivery expected between May 1 and May 15, 1974 and had nineteen ISIS kits to be delivered with an estimated delivery of fifty calendar days from the date of order. Mr. Clark was able to advise the court that ten of the new blades had been ordered before the accident and he believed that the nineteen ISIS kits had been ordered before the accident. In later testimony Mr. Clark was able to confirm that the work authorization relating to the nineteen kits is dated March 14, 1974.

185 It is clear on the evidence that DND could have moved more quickly in implementing ISIS. If it had, then perhaps the subject blade would have been equipped with the system on March 19, 1974, the date of the crash. However, in my view, the evidence does not support a conclusion that DND acted unreasonably in taking the time and steps that it did to consider Boeing's recommendation before making the decision to implement the system. The implementation of ISIS represented a major investment of public funds and one would have expected significant discussion at several levels over a period of time before the decision to commit to ISIS was made. In the meantime, the plaintiff was carrying out the inspection procedures recommended by Boeing for crack detection in rotor blade spars all as set out in Alert Service Bulletin A107-321 dated May 25, 1973 which was, in effect, at the date of this accident. I have already found as a fact that at the material time the plaintiff's x-ray technique had the capability to detect a through crack in the heel radius of a total length of 0.10 inch and that Canadian Forces was fulfilling the second prerequisite set out in A107-321, namely that it was using a VNE of 125 knots at a gross weight of 19,000 pounds or less thus requiring inspection of the rotor blade as per the recommendation of Boeing every seventy hours. Boeing had not recommended that non ISIS equipped blades not be used. Rather, it had recommended ISIS implementation and in the meantime had recommended x-ray inspection for cracks every seventy hours. As we know, the subject blade failed some 59.4 hours following its 2500 hour/4 year inspection and repair by the defendants.

186 In the circumstances, therefore, the "ISIS issue" is, in my view, not one which in any way effects or detracts from whatever right the plaintiff might have to recover from the defendants damages arising out of the loss.

THE EDMONTON X-RAY

187 As we have previously seen, subsequent to the 2500 hour/4 year inspection and repairs at Boeing U.S.A., the subject blade was delivered to Edmonton for service on a Canadian Forces helicopter. It was x-rayed in Edmonton on January 9, 1974 in order to bring it into the same rotation as its companion blades. The non-destructive testing report bearing that date is located at page 82 of the Board of Inquiry report (Tab 193, Exhibit 2). The report indicates that the x-ray technique used was 7 GX REV 2, that the purpose of the test was to determine if a crack existed in the D spar of the rotor blade and the test results are noted to be "NO DEFECTS INDICATED".

188 The Edmonton x-ray was marked as Exhibit 7B and was viewed during the course of Mr. Chapman's evidence. On viewing the Edmonton x-ray one can see that all of the corrosion that is shown in the Greenwood x-ray is gone and it is almost impossible to see the crack on the x-ray. Even with Mr. Chapman pointing me to the exact spot on the x-ray, it took me approximately five minutes to finally see the remaining flaw. Mr. Chapman in his evidence explained that the crack was more discernable in the Greenwood x-ray because it was in the cor-

rosion pit which tended to provide some contrast whereas in the Edmonton x-ray the rework (blending) had probably smeared the metal. It was Mr. Chapman's evidence that a viewer would have to be very lucky to find the defect in the Greenwood x-ray and it would be much less likely that a viewer would find it in the Edmonton x-ray even assuming that two people were reading the same x-ray. Mr. Chapman was of the view that it would be unreasonable to expect the crack to be detected on the Edmonton x-ray during the inspection of some forty films on the single blade. Again, he felt it highly unlikely that the crack would have been detected during routine inspection of the Edmonton x-ray due to the blending of the area, the presence of the de-icing blanket and the number of films to be reviewed.

189 In cross-examination, Mr. Chapman confirmed that when he looked at the Greenwood x-ray for the first time following the crash he saw evidence of corrosion and evidence of a crack. However, when he looked at the Edmonton x-ray for the first time following the crash he had a hard time finding anything but eventually was able to find the flaw.

190 It was Mr. Chapman's evidence that while the readers of both the Greenwood x-ray and the Edmonton x-ray failed to detect the crack, there was no deficiency in either 7 GX REV 1 (Greenwood) or 7 GX REV 2 (Edmonton) that in any way contributed to the failure to detect the crack.

191 Further Mr. Chapman was of the view that the Edmonton x-ray was technically suitable and was very close to the requirements of the Canadian Forces with respect to density and sensitivity.

192 Mr. Risk who was second in charge of the NDT unit at Edmonton at the material time, explained that in preparation for his testimony at the Board of Inquiry following the crash, he looked at the Edmonton x-ray and saw nothing unusual apart from the fact that the area had been worked down significantly during the course of Boeing's removal of the corrosion. In viewing the Edmonton x-ray during the course of this trial in the courtroom, he explained that the area of darkness on the right side of the x-ray which is the area where the crack occurred, indicated to him an area of reworking. He then viewed the area under high density light and again could see no evidence of any defect. It was his view that it was virtually impossible to see on the x-ray the crack that lay underneath the de-icing blanket. He was, however, satisfied that the x-ray itself was of sufficient quality to be used to detect a discontinuity. Mr. Risk was not at all surprised by the result indicated in the Edmonton non-destructive testing report dated January 9, 1974, that is, "NO DEFECTS INDICATED".

193 Mr. Tasseron in his evidence relating to the Edmonton x-ray expressed the view that a reasonable technician or reader at the time, looking at the Edmonton x-ray, would not have detected a problem in the blade.

194 Dr. Laister in his evidence confirmed the contents of paragraph 2.2.3 of his report dated April 1974 (Exhibit 53). The paragraph reads as follows:

> In the first instance the radiographs from Edmonton (9 JAN 74) were examined and some possible indication was found at the location of the crack; this was so slight that some uncertainty was imposed because of marks on the film. However, upon receipt of the films from Greenwood (5 FEB 73), the crack was plainly evident using a 10 x magnification. Photographs 31 through 34 are photographs taken from the radiographs.

195 Dr. Laister in his viva voce evidence explained that the "possible indication" discovered in the Edmonton x-ray was discovered by him using a 10 times magnifier.

196 Having regard to the weight of the evidence and having personally viewed the Edmonton x-ray, I am satisfied that there was no negligence on the part of the Edmonton technicians in the taking or reading of the Edmonton x-ray nor was there negligence on the part of any agent of the plaintiff relating to that x-ray that in any way contributed to the ultimate loss suffered by the plaintiff. On all of the evidence I have concluded that it would not have been reasonable to expect the readers of the Edmonton x-ray in 1974 to detect the remaining flaw.

DAMAGES

197 Barry Desfor was called by the plaintiff to testify with respect to the quantum of damages suffered by the plaintiff. Mr. Desfor is the owner and president of HeliValue$ Inc. His company is the publisher of the only official helicopter Blue Book in the world which provides resale values, specifications, operating costs, overall costs and costs of components with respect to one hundred different models of helicopter. As well, he performs

technical inspections and appraisals for prospective purchasers, investors, and banks. He first became involved with helicopters in the early 1960's when he joined the military and attended helicopter flight school. He was in the United States Army for some seven years and flew helicopters the majority of that time. He had two tours of duty in Vietnam as a helicopter pilot and as an instructor. After Vietnam he did charter and freelance piloting of helicopters and some instruction work. He was recruited in 1977 to come to Chicago by the original owners of the Blue Book who were then just in the process of formulating the concept and the Book itself. He was involved in its creation from the very beginning. Initially he was a field man inspecting and evaluating and supervising maintenance and gathering technical and retail information to go into the Blue Book. Eventually he incorporated his own company and purchased the Blue Book business from the original owners in 1990. The Blue Book is published annually with about four hundred pages and is updated two or three times each year by supplementary publications. It is sold in some fifty countries to manufacturers, engine manufacturers, accessory manufacturers, leasing companies and banks. It is the only one of its kind in the world. Mr. Desfor's appraisal services are purchased by a wide variety of interests including insurance companies and financial people. Mr. Desfor is widely published in various trade publications and is a frequent speaker at helicopter functions. He has appeared in court some twenty to thirty times and has provided opinions in forty to sixty pieces of litigation. He had appeared in the United States Courts at the Federal and State level in New York, Texas, Colorado, Utah and Louisianna and has appeared in the World Court at the Haag.

198 In presenting his evaluation, Mr. Desfor explained that the size of the helicopter playing field is very limited. In the entire world there are only twenty-five thousand civil/commercial helicopters and another twenty-five thousand military helicopters. This is really a very minuscule number when one understands that there are one quarter million fixed wing aircraft in the United States alone. He explained that one major evaluation point different for helicopters as opposed to fixed wing aircraft is the fact that the fixed wing aircraft have the majority of their values in the fuselage. Their fuselage is pressurized and this forces the fuselage to stretch and contract. By way of example, Mr. Desfor indicated that the Boeing 747 is eight inches longer in flight than it is on the ground. As a result of this stretching and contracting, there is a finite limit on the structure. On the other hand the majority of the helicopter's value is in its components, parts, and pieces. The helicopter is not pressurized, its structural life limit is much greater than a fixed wing aircraft and a great many of its components and pieces can be replaced without affecting the integrity of the helicopter. As well, in helicopters, there is a constant rotation of parts side by side with different relife periods so that in determining value the appraiser attempts to determine where each component is at in its life cycle. Mr. Desfor explained, as well, that most parts of a helicopter are overhaulable, that is, the part can be brought back to like new to start a new life cycle.

199 Mr. Desfor also explained that while the core value of the helicopter is in its parts, the parts do not change once the manufacturer designates a model. As long as the model is produced, there is absolute conformity both in body and in parts so that the parts are readily interchangeable between a 1965 model and a 1995 model of the same helicopter. Most helicopters were first designed for the military and most commercial helicopters are reasonably similar to the military type. Most military helicopters do not have civilian or commercial type certification.

200 Mr. Desfor was first retained by the plaintiff in 1992 to express his written opinion of the fair market value of the subject helicopter, a Boeing CH113A Voyageur helicopter, Serial No. 4007, at the time of its destruction on March 19, 1974. He explained that to proceed with his evaluation he had to make certain assumptions because the full documentation with respect to each component part of the helicopter was not available to him. He understood that the log books which had been maintained by Canadian Forces for the helicopter and which defined its configuration, serviceability and maintenance history had been disposed of by Canadian Forces following its investigation into the crash. His report which is dated August 6, 1997 and which was filed as Exhibit 36 in these proceedings does set out in paragraph 5 thereof of the FACTS, certain other documents that were available to him and from which he attempted to deduce the configuration, serviceability and maintenance history of the subject helicopter.

201 In arriving at his opinion Mr. Desfor noted that helicopters frequently appreciate in value following a period of several years from the time of their delivery as new helicopters. When helicopters are anywhere from six to ten years old it is not uncommon to see them reselling at prices which range from 105% to 150% of their original new cost. The price of a new helicopter predictably increases in each ensuing year and at any given time an old helicopter can do exactly the same work as an expensive new one. Mr. Desfor explained, as well, that often with new acquisitions there are bugs that have to be worked out resulting in significant down time

whereas such is not the case with older helicopters which have settled into a bug-free pattern. In the result the "older units" generally increase in value on a par with the percentage increase of the cost of their replacement parts. Again, most helicopter components can be repaired, overhauled and relifed and a renewed component has a very high value, approximately eighty percent of a duplicate new part.

202 Mr. Desfor explained that the component value of the helicopter has peaks and valleys because many parts are coming due for relife at different times. He explained that over time this would average out at about the fifty percent point. In other words, at any given time one can look at a collection of components and say that on average they have a value of fifty percent of either their replacement or overhaul costs.

203 It was clear from Mr. Desfor's evidence that there was as of the date of this loss, no resale market for the subject helicopter or one of its type. He readily admitted that, although in his report he talks about the fair market value of the helicopter, there was in fact no market value as such because none of the market conditions assumed for the purpose of determining fair market value existed at the time. For example, the assumption of active participation by a willing buyer/willing seller, in an arm's length transaction did not exist.

204 In the absence of any resale market for the subject helicopter or its type at the time of the loss, he considered this to be a special situation appraisal. The helicopter was one of a dozen others. It was one of limited production. There was no active record of resale and there had been no deliberate attempt to offer for resale. It was Mr. Desfor's view that in the absence of actual sale prices of new Voyageur helicopters at the date of loss or market data showing actual resale transactions for used Voyageur helicopters, there were two feasible valuation approaches that would be considered reasonable and proper and in accordance with accepted aviation equipment appraisal methodology.

205 The first approach involved referencing available market data for the "nearest comparable" used helicopter which has had a reasonably regular and traceable resale transaction record. Again, the fact of the matter is that there is no record of any resale transaction of a helicopter of the subject type. Mr. Desfor was of the view that the "nearest comparable" to the Voyageur was a Sikorsky S-61N helicopter. While the two helicopters had different rotor blades, flight control and transmissions, the Sikorksy's internal and external capacity, its range in speed, its empty and gross weight measurement and engines identical to the Voyageur, made the Sikorsky a functional duplicate of the Voyageur.

206 The excerpt from HeliValu$'s Inc. Blue Book published in 1979, which excerpt forms part of Mr. Desfor's report, indicates that in 1974 a new Sikorsky had a factory new list price of about $2,400,000. For the reasons set out in his report Mr. Desfor was of the view that the Voyageur, if it was being produced in 1974, would have had a higher factory list price.

207 The excerpt from the HeliValue$ Inc. Blue Book also shows that as at January 1979 a 1968 Sikorsky had an average resale value of $1.77 million, $1.91 million and $2.05 million depending on whether it had logged high time, mid time or low time respectively with respect to its component status. Mid time component status places the required maintenance, overhaul, and replacement of the moving parts at their fifty percent time used up point with fifty percent allowable service life remaining. It should be noted that the above values are expressed in U.S. funds.

208 The evidence then supports the conclusion that assuming "mid time" component status, a 1968 Sikorsky, eleven years later in 1979 had an average resale value of $1.91 million U.S. representing an increase of approximately sixty percent of the original factory new list price (1.203 million) over a period of eleven years.

209 It is of interest to note that the factory new list price of the subject helicopter, the Voyageur, was approximately $700,000.00 U.S. in 1963. See the original sale contract at Tab 1, Exhibit 2. Assuming the same rate of appreciation, that is sixty percent over a period of eleven years, its resale value in 1974 would be $1,120,000 U.S. Of further interest is the fact that in the Statement of Claim as originally issued in 1979, the plaintiff claimed to have suffered damages "in the amount of $1,200,000 being the value of the helicopter at the time of its destruction". Subsequently, it was not until shortly before trial that the plaintiff amended its Statement of Claim, claiming damages in the amount of $2.1 million.

210 The other approach used by Mr. Desfor in valuing the subject helicopter at the time of destruction was to attempt to reconstruct its replacement cost as of that time. In this approach Mr. Desfor brought forward what he called the "1965" contracted and delivered price of the helicopter to 1974. To do so, he computed the industry standard average yearly percentage increases of the prices for the helicopters, their kits, and their replacement

parts. This brought forward price was then reduced by Mr. Desfor by the dollar amount which represented fifty percent of the value of the components and the major installed optional kits so as to make allowances for its "mid time" status.

211 By this method Mr. Desfor took the original price of the subject helicopter in 1965 as being $990,858 Canadian. It is, however, to be noted that the purchase contract dated February 14, 1963, Tab 1, Exhibit 2, calls for delivery of seven helicopters in 1964 and five in 1965. As well, the contract calls for an estimated expenditure of approximately $9,150,000 Canadian which would appear to indicate an estimated expenditure of approximately $762,500 Canadian per helicopter. As well, the unit price of each helicopter was quoted as $696,612 U.S. (see page 5 of the contract). The exchange rate in 1964 was approximately 1.08 which would result in a unit price in Canadian dollars of something in the area of $750,000. Mr. Desfor's base price of $990,858 would be approximately $240,000 Canadian more than the Canadian unit price indicated in the contract.

212 In any event, to the base price of $990,858 Canadian, Mr. Desfor for the purpose of this approach, added over the period of nine years an eight percent increase in the value of the components (excluding the airframe) thus yielding a brought forward value in 1974 of $2.3 million Canadian. From this was deducted fifty percent of the increase in the value of the components due to the assumed "mid time" component usage. This amounted to approximately $375,000 Canadian yielding by Mr. Desfor's approach a reconstructed replacement cost in the range of $1.95 million Canadian for a "mid time" used Voyageur in 1974.

213 By way of generalities, Mr. Desfor acknowledged that if the subject helicopter had just come back from a major overhaul at Boeing U.S.A. (as it had) the evaluation could be effected upwards.

214 In the face of the evidence of Yoran Berg given on behalf of the defendants and which evidence will be reviewed in due course, Mr. Desfor readily conceded that the subject helicopter was not certifiable as a passenger plane, that it was designed for the military with only a possibility of ending up in restricted commercial use and that if it did so end up, it would not have the same value commercially as it would have in the military. Mr. Desfor disclosed that he knew of no possible military market for the subject helicopter in 1974 for resale and that any resale into the commercial field would be extremely limited.

215 In cross-examination Mr. Desfor conceded that he had very limited information with respect to the life status of the various components of the subject helicopter and based his appraisals on an assumption of the components being at mid life. He conceded that if the plaintiff had been able to make the appropriate logs available to him, then he would not have had to proceed by way of assumption but could have determined from the logs the life stage of the components.

216 In cross-examination Mr. Desfor was unable to give specifics as to the actual price increases that he looked at in order to determine the average yearly percentage increase of eight percent in the value of the components. He testified that he did look at many commercial and military helicopters in arriving at that number but was unable to identify his sources.

217 At the conclusion of his report and of his evidence Mr. Desfor was of the opinion that the fair market value of the subject helicopter at the time of its destruction in 1974 was between $1.9 million Canadian and $2.1 million Canadian.

218 As well, in cross-examination, in referring to Tab H of his report, the 1979 excerpt from the HeliValue$ Inc. Blue Book, he agreed that the page included a notation that $180,000 U.S. should be deducted from the values shown if the Sikorsky was a land model as opposed to the amphibious model. He conceded that the subject Voyageur was not an amphibious and that possibly the "nearest comparable" should be a Sikorsky land model.

219 Mr. Crawley in his evidence had been asked by plaintiff's counsel to address the value of the subject helicopter to Canadian Forces at the material time. He explained that immediately prior to the crash it was fulfilling a role with a scheduled number of missions per month. He explained that after the crash the missions did not go away and with the shortfall in the fleet, additional craft had to be assigned as search and rescue. A role existed for the lost craft and that role had to be completed by other craft that filled the gap. He explained as well that there is an intermilitary market for aircraft which in fact is less restrictive than the commercial market because there are no government restrictions on use of military craft. He explained that in 1974 the long term plan with respect to Voyageur helicopters was to phase them out by 1995. That phase out date has now been

extended to 2003 or 2004. He explained that if the subject helicopter had not been lost in 1974 it would have been in active service in a search and rescue squadron today. He explained that Canada has sold or disposed of aircraft to other countries in the past. He explained that an aircraft is a Crown asset that is not sold necessarily on a cash basis. Often there are trade offsets and partner assets to be considered so that it is generally difficult to assess cash value of any disposition.

220 Keith Serkes was called by the plaintiff to give evidence with respect to the value of the lost helicopter. Mr. Serkes is licensed as a pilot, a flight instructor, and flight engineer and has experience with respect to most of the common helicopters in service today. He is President of Aircraft Appraisers Inc. and a member of the National Association of Aircraft Appraisers. He readily conceded in his evidence that a significant portion of his work which involves the evaluation of perhaps one hundred helicopters per year is funneled through Mr. Desfor's company HeliValue$. Mr. Serkes was supportive of Mr. Desfor's methodology and valuations.

221 Gorn Berg gave evidence for the defendants with respect to the value of the subject helicopter. From 1967 to 1970 Mr. Berg worked as an engineering officer with the Swedish Air Force and was involved with the 107 type helicopters being operated by the Swedish Air Force and Navy. After he left the military in 1970 he joined a Swedish company acting as agent for Boeing and Kawasaki which was a Japanese licencee of Boeing. As such, he was the product manager for the sale of seven Kawasaki 107's to the Swedish Navy. He stayed with that company until 1985 and then went with a company known as Caribou Aviation as agent for Kawasaki. He now acts as agent for Eurocopter which makes helicopters similar to the 107. He has approximately thirty years experience with the 107's and has been involved in selling second hand helicopters. He is familiar with the Sikorsky 61 series and pointed out that Sikorsky was a competitor with Boeing when bidding for the Swedish Navy contract.

222 Both in correspondence and in the course of viva voce evidence, Mr. Berg was asked to address the following questions.

(a) What market, if any, existed for this type of aircraft in March of 1974.
(b) What resale valuation could he put on this aircraft as of March 1974.
(c) Do you have an opinion as to whether the value of the subject aircraft would have appreciated over the years of service between 1964/65 and March 1974.

223 In response to those questions Mr. Berg testified as follows.

(a) The market for the subject type of helicopter was and still is very limited. It is not possible to compare the subject helicopter with the Sikorsky S61 as the latter became quite popular as a passenger transport helicopter.
(b) In his view there did not exist a second hand market for the subject helicopter as of March 1974.
(c) In 1974 the subject helicopter was almost ten years old having operated almost 3500 hours of service. In Mr. Berg's view a civil operator would typically have depreciated the helicopter to at least fifty percent of the purchase price, i.e. approximately $350,000 U.S.

224 In cross-examination Mr. Berg conceded that there were no second hand helicopters available for sale at the time because the military bought them with a view to using them for a very long time. He acknowledged that a helicopter similar to the subject helicopter purchased new today would have a purchase price of something in the order of $15,000,000. He conceded that in expressing his views as to valuation, he did not apply any appraisal techniques nor did he consider any intrinsic value or trade value that the helicopters might have to the Canadian Government.

225 It is clear on all of the evidence that in 1974 there was no market for used military helicopters and indeed the market for the type of subject helicopter in the last twenty five years has been extremely limited.

226 I accept Mr. Desfor's evidence on the point and find as a fact that helicopters generally appreciated in value following purchase as new from the factory. That fact is demonstrated by the resale history of the Sikorsky S-61N as documented by Mr. Desfor. As well, I accept Mr. Desfor's evidence on the point and find that in 1974 the nearest comparable commercial model helicopter to the subject helicopter was the Sikorsky S-61N (subject to the caveat that the Voyageur was not amphibious). I agree with the submissions of counsel for the

defendants that in view of the fact that the Sikorsky was not manufactured until 1968, it is problematic to simply arrive at the value of the subject helicopter as of 1974 based on this comparison.

227 In determining the actual value of the subject helicopter to the plaintiff at the time of the loss, I must have regard to all of the conditions and circumstances then existing, not necessarily its market value on the one hand or on the other its "replacement value". See Canadian National Fire Insurance Company v. Colonsay Hotel Company [1923] S.C.R. 688 at page 694.

228 In all of the circumstances I am inclined to the view that the fairest approach to the assessment of the plaintiff's loss (that is the fairest approach to both the plaintiff and the defendants) is to determine the cost of its acquisition and to then apply a reasonable appreciation factor for the intervening years to 1974.

229 As best I can determine from the evidence and particularly the purchase contract dated February 14, 1963, the cost of acquisition was $696,612.00 U.S. As previously indicated the exchange rate in 1964 was approximately 1.08 which would result in a unit price in Canadian dollars of approximately $750,000.

230 In arriving at a reasonable appreciation factor, I note that the Sikorsky in an eleven year span from 1968 to 1969 appreciated in value from $1.2 million to $1.9 million (mid time) an increase of approximately sixty percent over an eleven year period. Assuming this would be a reasonable rate of appreciation to apply to the subject helicopter, over the eleven year period from 1963 to 1974 its value would have appreciated from $750,000 to $1,200,000.

231 I must take into consideration Mr. Desfor's evidence that the Sikorsky in comparison with the subject helicopter was a less expensive helicopter brand new and less expensive to maintain. As Mr. Desfor notes in his report:

> The S-61 N's systems were less complex and therefore less expensive to acquire, operate or maintain compared to the Voyageur's similar parts.

232 I must also consider that the evidence is clear that there was a significant resale market for a used Sikorsky such that the Sikorsky warranted an entry in the helicopter Blue Book while there was no resale market for the subject helicopter.

233 I agree with counsel for the defendants that such differences would likely have a positive effect on the value and demand for the Sikorsky and on the appreciation rate over an eleven year period.

234 Taking all of these factors into consideration, I have concluded that an reasonable assessment of the plaintiff's loss as a result of the crash of the subject helicopter in March of 1974 was $1,000,000 Canadian.

235 In the result I have arrived at the following conclusions.

CONCLUSIONS

1. The plaintiff was negligent in failing to adequately instruct its technicians with respect to the significance of corrosion on the D spar of the blade and in failing to ensure that the x-ray review called for in the directive dated September 21, 1973 was properly conducted and thus contributed to the eventual failure of the blade and loss of the subject helicopter.
2. Boeing Canada was in breach of its contract with the plaintiff in failing to ensure that the reworked area on the spar of the blade was examined by way of magnetic particling following the rework and Boeing U.S.A. was negligent in failing to apply non-destructive testing to the reworked area after rework. Boeing Canada's breach of contract and Boeing U.S.A.'s breach of common law duty contributed to the ultimate failure of the subject blade and the loss of the subject helicopter.

236 In terms of apportionment there is little to choose between the degree of fault on the part of the plaintiff and that on the part of the defendants. With respect to the plaintiff, its technicians discovered corrosion on the Greenwood x-ray but because of ignorance on the part of the technicians in respect to the significance of corrosion, which ignorance was due entirely to the failure of the plaintiff to properly instruct its technicians, the blade was passed and put back in service. Had the technicians been aware of the risk of a crack associated with cor-

rosion, they may well have detected the crack on the x-ray. At the least, a properly informed technician would have prepared an unsatisfactory condition report and forwarded the blade and report on for further disposition. As well, had the plaintiff insured that the x-ray review called for in the September 21, 1973 directive been completed, it is likely that in the final result the blade would have been taken out of service.

237 On the other hand the defendants were made fully aware of the fact of corrosion on the blade spar by reason of Boeing U.S.A.'s inspection at the Boeing plant. Having discovered and removed that corrosion Boeing Canada through its subcontractor breached its contract and Boeing U.S.A. breached its common law duty to the plaintiff in that the reworked area was not subjected to magnetic particling or any other type of localized non-destructive testing to determine whether there was an underlying crack. Again, it is clear from the evidence that Boeing U.S.A. notwithstanding the clear appreciation that it had as to the significance and risk of spar corrosion, had never instructed its technicians on the plant floor as to the significance of corrosion and the risk of an underlying crack. It is probable that had magnetic particling or some other localized non-destructive testing been applied to the reworked area after rework at the Boeing U.S.A. plant, then the crack would have been detected.

238 Even without recourse to Section 4 of the Negligence Act, I have come to the conclusion on all of the evidence in this case that the damages sustained by the plaintiff have been contributed to equally by the plaintiff on the one hand and the defendants on the other.

239 In the circumstances the plaintiff will have judgment against the defendants for the sum of $500,000.00 Canadian.

240 I may be spoken to with respect to the matter of prejudgment interest and costs as well as the plaintiff's motion to amend if required.

G. MORIN J.

qp/d/alp/DRS

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Time Of Request: Thursday, July 23, 2009 11:43:03