Failure Analyses of Aircraft Accidents—
Part I

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This report covers case histories of failures in fixed-wing light aeroplane and helicopter components. Investigated during a five-year period, these cases represent various modes of failures and describe remedial actions taken to assure flight safety. Material failures were due mainly to either of both improper maintenance (or overhaul) and insufficient inspection.

SERIOUS accidents or incidents may result from failures during any phase of aircraft operation. Recognition of the source of premature or incipient failures is important as appropriate corrective action must be taken to prevent future failures on other aircraft.

The total number of registered aircraft and accidents to Canadian aircraft is shown by year in Fig. 1 to indicate trends since 1959. Accident data in two categories, scheduled and non-scheduled airlines, are also illustrated. Most accidents occurred to non-commercial aircraft, specifically private planes.

A comprehensive analysis of assigned accident causes indicates that approximately 72 pct of accidents are caused by personnel (pilot or maintenance), 20 pct by technical failures, and 4 pct by environment (weather or terrain); causes for the remainder are undetermined. A high percentage of these accidents occurred during landing.

From 1966 to 1970, the Engineering Laboratory of Aircraft Accident Investigation Division received 419 projects for failure analysis; 295 of these were
material failures. In addition, there were many mechanical failures involving incidents, and a large number of unreported failures involving replacement or repair on a warranty or normal replacement basis. Major material failure problems were found in power-plant and landing gear components.

MATERIAL FAILURES SUMMARY

Results of five years of laboratory investigations (Tables I and II) emphasize the significance of fatigue and maintenance problems in the operation of aircraft equipment, and the need for more care in the overhaul, operation, design, and fabrication of materials.

<table>
<thead>
<tr>
<th>Type of Component</th>
<th>Fatigue</th>
<th>Overload</th>
<th>Corrosion, hydrogen embrittlement</th>
<th>Excessive wear, deformation</th>
<th>Miscellaneous, high temperature, rolling, etc.</th>
<th>Improper material and inspections</th>
<th>Inadequate design or maintenance instructions</th>
<th>Manufacturing deficiencies</th>
<th>Abnormal operation or service damage</th>
<th>Undetermined</th>
<th>Total by Component</th>
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<tbody>
<tr>
<td>Powerplant</td>
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<td>12</td>
<td>-</td>
<td>11</td>
<td>17</td>
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<td>22</td>
<td>9</td>
<td>27</td>
<td>9</td>
<td>109</td>
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<td>30</td>
<td>58</td>
<td>5</td>
<td>-</td>
<td>2</td>
<td>20</td>
<td>22</td>
<td>3</td>
<td>45</td>
<td>9</td>
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<td>6</td>
<td>7</td>
<td>2</td>
<td>7</td>
<td>-</td>
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<td>3</td>
<td>-</td>
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<td>1</td>
<td>17</td>
<td>-</td>
<td>8</td>
<td>4</td>
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<td>21</td>
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<td>Structural Members and</td>
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<td>-</td>
<td>5</td>
<td>2</td>
<td>4</td>
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<td>13</td>
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<td>-</td>
<td>4</td>
<td>4</td>
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<td>5</td>
<td>1</td>
<td>18</td>
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<tr>
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<td>-</td>
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<td>Total by Type</td>
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<td>104</td>
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<td>12</td>
<td>30</td>
<td>91</td>
<td>62</td>
<td>25</td>
<td>107</td>
<td>10</td>
<td>295</td>
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</tbody>
</table>

Fig. 1—Numbers of Canadian civil aircraft, total accidents, and accidents in two categories; 1959 to 1970.
GROUP 1: CRANKSHAFT FAILURES FROM SMALL OPPOSED ENGINES OF LIGHT AIRCRAFT
(AISI 4340 steel, heat-treated and nitrided all over)

Most premature failures occur for well understood reasons, and should have been prevented. The majority of service failures are really "people failures"; personnel in aircraft maintenance and repair facilities, including operators, should learn from these errors. Because it is their responsibility, operators should make sure that adequate maintenance is performed at required intervals. Proper use of appropriate nondestructive tests and careful routine inspections would have eliminated about 60 pct of the failures experienced, it is felt.

In this summary, the cause for a specific failure type is assigned according to one major factor resulting in failure initiation. Wherever the evidence regarding the main cause of a failure was not conclusive, some judgment entered into the classification. The exact number of failures due to each specific cause could not be ascertained because, in many instances, the failure could be placed in more than one of the broad categories.

CASE HISTORIES

Fourteen sample groupings of repetitive types illustrate representative case histories of material failures in different kinds of aircraft components. Many groups contain two examples of a specific failure mode according to a form or forms of specific source. In each group, other components experiencing similar failures are also mentioned. Components have been selected on the basis of failure modes to

Fig. 2—Typical fracture face of crankshaft which failed by bending fatigue. Note origin at fillet and distinct "beach marks".

Fig. 3—Magnetic particle indications of parallel cracks (indicated by arrows) and network 'checks' (typical of grinding damage) on fillet surfaces of a failed (left) and whole journal. Magnification 2.20 times.

Fig. 4—Grinding burn area (hard, brittle white layer of untempered martensite; Rc 54 to 56) and microcracks (arrows) on fillet surface near fatigue origin. Magnification 75 times; 2 pct nital etch.
Table II. Material Causes and Basic Mechanisms of Aircraft Failures

<table>
<thead>
<tr>
<th>Assigned Main Causes</th>
<th>Fatigue</th>
<th>Overload</th>
<th>Corrosion, Stress corrosion embrittlement</th>
<th>Excessive wear, deformation</th>
<th>Abrasive wear, galling, etc.</th>
<th>Total by cause</th>
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<tr>
<td>Inadequate Maintenance, Overhaul, or Inspections</td>
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<td>12</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>91</td>
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<tr>
<td>Inadequate Design or Maintenance Instructions</td>
<td>64</td>
<td>12</td>
<td>6</td>
<td>3</td>
<td>6</td>
<td>91</td>
</tr>
<tr>
<td>Manufacturing Deficiencies</td>
<td>44</td>
<td>10</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>62</td>
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<td>Abnormal Operation or Service Damage</td>
<td>16</td>
<td>6</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>25</td>
</tr>
<tr>
<td>Undetermined</td>
<td>11</td>
<td>75</td>
<td>–</td>
<td>2</td>
<td>19</td>
<td>107</td>
</tr>
<tr>
<td>Totals by Type</td>
<td>140</td>
<td>104</td>
<td>9</td>
<td>12</td>
<td>30</td>
<td>295</td>
</tr>
</tbody>
</table>

Eleven groups cover fatigue failures, each emanating from a specific source. The twelfth group shows the difference between stress-corrosion cracking (SCC) and intergranular corrosion (IC); the thirteenth group, two examples of hydrogen-induced brittle failure (hydrogen embrittlement) and the final group, an example of abnormal wear.

It should be noted that all of these cases of service failures were involved in accidents or incidents. Fracture analyses, checks of mechanical properties, and metallographic studies help to determine why the components failed in service.

FAILURES IN CRANKSHAFTS

Fig. 2 illustrates a crankshaft of AISI 4340, heat treated and nitrided all over, which failed in bending fatigue. The cause was grinding damage; the nitrided layer was ground too rapidly causing excessive heat generation which induced grinding cracks (Fig. 3) and grinding burn (Fig. 4). Regrinding was not performed. Tensile stresses resulting from grinding developed in a thin surface layer.

On another crankshaft, from a 4-cylinder engine of a small plane, metallurgists noted a thick (about 0.010 in.)...
GROUP 2: LIGHT AIRCRAFT METAL PROPELLER BLADE FAILURES
(Aluminum alloy 2000 series, usually 2025-T6 or 2219-T6)
Hardness values found: 68/72 R_B, 98-100 R_P, 128/138 DPH.

In some instances no nick was found, but the origin corresponded to a zone which had been deeply dressed out (leaving coarse file marks in one instance) during the previous overhaul.

Fig. 9—Propeller blade failed near the tip. Material: 2025-T6 or 2219-T6; hardness: DPH 128 to 138.

Fig. 10—Typical fatigue fracture face of a propeller blade. Note nick (or stone bruise cut) at the O (origin) on the leading edge of the blade's rear face.

Fig. 11—Dressed-out area on the blades' leading edge (arrow) coincides with failure origin. Inset depicts nicks and pits adjacent to origin.

Fig. 12—Initial portion of fatigue failure shown in Fig. 11. Arrow indicates direction of crack growth.

Fig. 13—Fatigue crack growth started at O; arrows indicate direction. Magnification 3 times.

In.) chromium plate with a multitude of cracks; microcracks and grinder's scorch marks were found under it (Figs. 5 to 8). Improper journal radii and loss of nitrided case were detected. As chromium plating may introduce undesirable residual tensile stresses, it is an unsatisfactory finish for crankshafts of aircraft engines.

Fatigue failures in crankshafts of small engines can also be caused in other ways. For example, propeller contacts with the ground would cause internal damage, and result in thrust line misalignments. Fatigue failures have also developed from small cracks in case hardened or plated surfaces. (Cracks of this type are usually very small, but their stress...
Fig. 14—Secondary crack (arrows) on the leading edge of blade, starting about 3/16 in. away from fracture of Fig. 13. Magnification 2 times.

Fig. 15—Fracture face of secondary crack, Fig. 14. Note similarity to primary fracture, Fig. 13. Magnification 4.45 times.

Fig. 16—Face of fatigue fracture in propeller blade. Note beach and river markings pointing to origin.

Fig. 17—Tiny pit (arrow) led to fatigue fracture in blade. Concentrating effects are so great that a fatigue failure can occur in several hours of engine time after the crack starts.

To alleviate this problem, aircraft engine manufacturers and aeronautical standards require magnetic particle inspection to detect grinding cracks after reconditioning. Renitriding after any grinding is also needed regardless of the amount of undersize as it introduces beneficial residual compressive stresses, thereby increasing the fatigue life of a part. Chromium plating is prohibited, it is emphasized.

DAMAGED PROPELLER BLADES

Blade damage (such as stone nicks or bruises, dents, pits, insufficiently removed nicks or gouges, and deeply dressed-out zones) can be present before an accident or incident. In a typical instance, (Figs. 9 to 12), cracks started on the leading edge at surface damage in the critical area—the zone between 4 and 10 in. from the tip of the blade. In this zone, normal tensile and vibratory bending loads are highest. Incorrect dressing and inadequate pre-flight inspection are the two main causes. Also, propellers with damaged blades were probably being operated continuously at a speed which produces high levels of vibration and stress.

To eliminate blade tip failures, the following procedure should be followed:
1. Examine the critical area closely during each pre-flight inspection.
2. If any nicks, dents, deep pits and the like are observed, remove all surface-damaged material, and polish smooth (without leaving any coarse file marks) before further flight. Perform correct dressing.
3. Have the tachometer calibrated to assure the engine/propeller combination is not operated in the critical speed range at normal cruising speeds.

Shown in Figs. 13 to 18 are two other types of propeller blade fatigue failures. Both mainly result from propeller straightening operations, usually performed after previous blade bending damage.