DEPARTMENT OF COMMERCE
Washington
National Bureau of Standards

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Preliminary Report on Examination of a Broken Cylinder from a Pratt and Whitney Twin Wasp SB3-G Aircraft Engine Submitted by Bureau of Air Commerce Washington, D. C.

This preliminary report contains the essential observations and conclusions by the National Bureau of Standards of a broken aircraft engine cylinder submitted in accordance with a letter, dated June 3, 1938, from the Bureau of Air Commerce.

The cylinder, which was submitted in three pieces, showed two characteristic types of failure. One type of failure was a fatigue fracture which originated on the to-side of the hold-down flange, in the immediate vicinity of the clearance space cut into the fillet in the angle between the flange and cylinder wall. The characteristic markings of a fatigue fracture were plainly evident on the surfaces of fracture in the hold-down flange, which was completely severed in a direction at an angle to the axis of the cylinder. The shape of these markings indicated that the origin of the fatigue fracture was most probably in the clearance cut, as stated above. The fatigue fracture had progressed from the flange through the cylinder wall, and extended around the cylinder in a diagonal direction, for approximately one-fourth of the circumference.

The remainder of the fractured surfaces showed the characteristics of failure under excessive tensile load, combined with bending of the cylinder walls and battering of the surfaces of fracture.

The fact that the cylinder barrel was bent, crushed, and torn was evidence that the material was ductile and not brittle.

The fact that the fracture through the hold-down flange in a ductile metal had occurred without any deformation at the point of fracture was substantiating evidence that the original fracture was a fatigue fracture, originating at a point of localized maximum stress, and advancing under the action of repeated stresses, and had not occurred as the result of a single application of force sufficient to rupture the metal suddenly.

The angle between the top side of the hold-down flange and the cylinder wall had been rounded with a fillet indicated to be 1/4-inch radius on the approved drawing of the cylinder, No. C-21804, and found by inspection to be in accordance with the drawing. However, at each hole for the hold-down studs, the fillet had been cut back, apparently to make clearance for the nut, so that practically all of the fillet had been cut away It is a well-known fact that stresses across an abrupt change in section are much greater than when a more gradual change in section is provided by an adequate fillet.

In addition to the stress-raising effect caused by cutting back into the fillet, a further, and possibly more severe localized stress concentration effect was caused by the rough machined surface in the clearance cuts at the stud holes. At one of the bolt holes the surface of the clearance cut contained a fissure which was much deeper and longer than the tears and gouges found elsewhere on the roughly machined clearance cuts. All other surfaces of the cylinder which had been finished with machine tools appeared fairly smooth, even when observed under low-power magnification. Observed at the same magnification, the metal at the surface in the clearance cuts was torn and rough. This type of surface, in parts subjected to repeated stresses, is known to reduce greatly the resistance of the part to fatigue failure.

A specimen for chemical analysis of the steel was cut from the top portion of the cylinder barrel. The results of the chemical analysis and the composition specified in Pratt and Whitney Aircraft Company Specification PWA185 (SAE 4140) were as follows -

Pratt and Whitney Aircraft Company Specification PWA185 (SAE 4140)		Results of Analysis by National Bureau of Standards
0.35 to 0.45 percent	Carbon	0.40 percent
.50 to .80 "	Manganese	.75 "
.050 Maximum "	Sulphur	02 "
.040 " "	Phosphorus	less than 04 "
Not specified	Silicon	.24 "
.80 to 1.10 percent	Chromium	.91 "
15 to .25 "	Molybdenum	.24 "

The results of the chemical analysis showed that the steel conformed to the requirements for chemical composition as given in Pratt and Whitney Aircraft Company Specification PWA185, for chromium-molybdenum steel (SAE 4140).

The dimensions of the cylinder, in so far as they were checked at the Bureau, conformed, within the permitted tolerances, to the dimensions given in the approved drawing of the cylinder, No. C21804.

Without cutting away portions of the cylinder from the part which, it was agreed, was to be preserved intact as submitted to this Bureau, it was possible to make an indentation hardness test by the standard Brinell method at only one point, on the hold-down flange. The Brinell number obtained was 285, which was, within experimental tolerance, the low end of the range 286 to 321 specified in approved drawing of the cylinder, No. C-21804.

Vickers numbers, approximately equivalent to Brinell numbers, obtained on specimens used for metallographic examination were as follows:-

1. Specimen of cylinder wall close to origin of fatigue fracture -

Vickers No. 30 kg load on 136° diamond pyramid

287

284

292

2. Specimen from cylinder wall, slightly above hold-down flange -

Vickers No. 30 kg load on 136° diamond pyramid

303

311

3. Cross-section of hold-down flange, same load and diamond -

Vickers No. 301

Although the Vickers numbers obtained on one specimen from the cylinder wall were slightly higher than those obtained on other specimens, the Vickers numbers likewise showed that the steel conformed to the specified requirements for hardness.

It was not practicable to obtain specimens for tensile tests, impact tests or other types of strength tests.

Under the caption "Physical Properties" the Pratt and Whitney Specification PWA 185 states "Material exhibiting physical defects, such as seams, tears, grooves, laminations, slivers, pitting ---- will be rejected." No evidence of such defects were found in the failed cylinder.

Metallographic examinations were made on specimens cut from portions of the cylinder close to the point of origin of the fatigue fracture, from portions close to the course of the fatigue fracture, and from portions remote from any of the factured surfaces. Some of the specimens had been removed from the cylinder and prepared for metallographic examination elsewhere, before the cylinder was submitted to the Bureau. These were repolished and re-examined at the Bureau, the results agreeing with the results obtained elsewhere.

The steel, in all of the specimens examined, contained numerous non-metallic inclusions for the most part fairly uniformly distributed, and of a fairly uniform size. Each of two of the specimens examined contained also one or more large non-metallic inclusions of a size not normally found in alloy or plain carbon steels of a quality considered satisfactory for parts of aircraft engines, such as crankshafts, connecting rods, etc. which are subjected to fatigue stresses.

It is generally conceded that large non-metallic inclusions, such as those found in several of the specimens from the failed cylinder, when located in regions subject to repeated stresses, constitute points of localized weakness which may decrese the resistence of the material to fatigue fracture.

The microstructure of the steel, as revealed by suitable etching of the polished specimens, was rather coarse grained, a condition which is not necessarily detrimental to the physical properties, and may be desirable for reasons such as providing satisfactory machining qualities.

In the opinion of this Bureau, at least two factors contributed to the failure of this cylinder. These were -

1 The clearance cuts in the fillet at the bolt holes which produced a region of high stress concentration.

2. The accentuation of this stress concentration by the rough machining of these clearance cuts.

These features are known causes of fatigue failure in parts subject to alternating stresses. That they were major factors in causing the failure of this cylinder is confirmed by the existence of fatifue fractures originating in the clearance cuts at two hold-down stud bolt holes in the flange of another cylinder of the same design from another engine.

In the opinion of this Bureau, the large non-metallic inclusions found in two of the specimens examined may have constituted a third factor contributing to the failbure. However, no evidence was found of the presence of large non-metallic inclusions at the point of origin of the fatigue fracture.

No evidence was obtained, in the examinations and tests performed at the National Bureau of Standards on the material of the submitted cylinder, of any departures, exceeding the permitted tolerances, from the specific requirements given in the approved drawing of the cylinder, No. C-21804 and Pratt and Whitney Specification, PWA 185 (SAE 4140) chromium-molybdenum steel.

(Signed) L. J. Briggs

Lyman J. Briggs, Director.