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TESTS OF CAST ALUMINUM-ALLOY MIXED-FLOW IMPELLERS

By John E. Douglas and Irving R. Schwartz

Aircraft Engine Research Laboratory
Cleveland, Ohio

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NACA AIRCRAFT ENGINE RESEARCH LABORATORY

MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

TESTS OF CAST ALUMINUM-ALLOY MIXED-FLOW IMPELLERS

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SUMMARY

A machined mixed-flow centrifugal impeller of relatively complex passage shape was used as a pattern to cast a number of aluminum-alloy impellers from two aluminum-base alloys (designated alloys 1 and 2) by the "lost wax" process. An investigation was conducted to determine whether these cast impellers could be considered satisfactory for use in compressors. The investigation included preliminary examination, physical tests, metallurgical examination, and performance tests.

The peak adiabatic efficiencies of the cast impeller with a vaneless diffuser were 2 to 3 points lower than the peak efficiencies of the machined impeller with a vaneless diffuser at comparable tip speeds. The cast impeller with the vaneless diffuser showed slightly lower peak pressure ratios and pressure coefficients than the machined impeller with the vaneless diffuser.

X-ray examination of the hubs of the impellers showed that five of the six impellers of alloy 1 and one of the six impellers of alloy 2 were without serious defects and would be considered sound castings. During the spin tests, the sound impellers of alloy 1 failed at tip speeds between 1641 and 1743 feet per second as compared with 1184 feet per second for the only sound impeller of alloy 2. Tensile tests of specimens obtained from the impellers show that the two alloys had approximately the same strength; the average tensile strength of the specimens of alloy 1 was 23,260 pounds per square inch and that of the specimens of alloy 2 was 20,900 pounds per square inch. The maximum elongation of the

specimens of alloy 1 was 4.5 percent whereas no elongation of the specimens of alloy 2 could be measured. The results of this investigation showed that impellers of alloy 1 cast by the "lost wax" process are suitable for use in superchargers up to tip speeds of at least 1200 feet per second.

INTRODUCTION

Impellers for air compressors of the type used in aircraft reciprocating-engine superchargers and gas-turbine installations are usually forged and machined, a manufacturing process that is especially costly in the fabrication of the complex shapes required for units of good efficiency and flow capacity. In an attempt to reduce this cost and to facilitate production, the Bureau of Aeronautics, Navy Department, instituted a program to determine the practicability of casting impellers by the "lost wax" method, similar to the process described in reference 1. In order to give the method the rigid test of a complex shape, the impellers were modeled after a mixed-flow centrifugal impeller with backward-swept blades. This machined impeller was tested at the NACA Langley Field laboratory. The NACA Cleveland laboratory was requested to study a group of 12 cast impellers provided by the Bureau of Aeronautics, six each of two different aluminum-base alloys, 1 and 2.

The impellers were examined visually and by X-ray. Eleven impellers were spin-tested to destruction and then subjected to physical and metallurgical examinations to determine their various properties, such as tensile strength, elongation, hardness, and grain structure. One impeller was tested in an NACA variable-component supercharger test rig to determine the performance when used in combination with a vaneless diffuser and the results were compared with the results of the similar tests of the machined impeller conducted at Langley Field. The results of the physical and metallurgical tests are presented in tables and photographs and the results of the performance tests of the two impeller-diffuser combinations are presented by standard performance curves. The effect of elevated temperatures and induced vibrations on the strength characteristics of the impeller materials was not directly investigated but some indications of these effects can be obtained from results of the performance tests.

APPARATUS

Impellers. - Twelve mixed-flow impellers were cast by the lost wax process using a machined experimental centrifugal impeller as a master pattern. This impeller is of the mixed-flow type with 23 backward-swept blades. It was designed to discharge the air with an axial velocity component. Unlike the conventional centrifugal impeller, the blades do not have abruptly curved sections at the inlet. Because of the shape of the impeller passage, the angular acceleration of the air is continuous along a radius; the angular velocity of the air, however, is always less than that of the impeller. A typical cast impeller furnished by the U. S. Naval Engineering Experiment Station, Annapolis, Md., is shown in figure 1. The feeder flange, which was removed from the finished impeller, supports the blade tips and helps prevent warping during the heat-treating process.

The cast impellers are smaller than the machined impeller owing to the shrinkage effects of casting. Furthermore, the outer edges of the blades of the cast impeller used for performance tests had to be machined to eliminate most of their irregularities. As a result, the cast impellers had a reduced passage area and inlet and outlet tip diameters. The inlet and the maximum outlet diameters of the cast impeller were 7.96 and 10.89 inches as compared with 8.25 and 11.36 inches for the machined impeller, respectively. Inasmuch as the passage interior of the cast impeller was not machined, the passage is not geometrically similar to that of the machined impeller because shrinkage altered the rate of change in passage area along the flow path through the impeller.

Six impellers were cast from each of the two aluminum alloys. The first alloy had 10 percent magnesium content while the second alloy had 7 percent silicon and 0.3 percent magnesium chemical composition. For simplicity and ease in handling the following discussion, these two aluminum alloys will henceforth be called alloys 1 and 2, respectively. Alloy 1 has high tensile strength (42,000 lb/sq in.) whereas alloy 2 is of lower strength material (26,000 lb/sq in.). In general, alloy 1 is more difficult to cast than alloy 2.

Diffusers. - A 34-inch vaneless diffuser, that was used with the cast mixed-flow impeller was designed to have an area expansion of a 6° equivalent cone along a logarithmic spiral flow path through the diffuser at design load. This diffuser design was also used with the machined impeller. The throat ratio of the vaneless diffusers (ratio of passage width at the diffuser entrance to passage width at the impeller tip) was increased from 0.534 for the diffuser used with the machined impeller to 0.748 for the diffuser used with the cast impeller. This change was made in order to obtain the best performance from the cast impeller with a vaneless diffuser on the basis of test results from the NACA Langley Field laboratory of a similar mixed-flow impeller with diffusers of various throat ratios. Figure 2 is a drawing of the cast impeller with the vaneless diffuser.

Spin rig. - An impeller spin rig was used to spin the cast impellers to destruction. A small air turbine (5 hp) was used to drive the impeller, which was mounted in an evacuated chamber. The impeller was suspended from the turbine and driven through a 1/4-inch-diameter vertical spindle. The walls of the evacuated chamber were 11 inches thick: first 4 inches of wood, then 4 inches of laminated steel, and then a 1-inch air gap enclosed by 2-inch boiler plate. The speed of the impeller was controlled by varying the pressure drop across the turbine. The rotational speed of the impeller and turbine was measured by a frequency meter within ±5 revolutions per second.

Variable-component supercharger test rig. - The impellers with the vaneless diffusers were tested in the variable-component supercharger test rig described in reference 2. The collector case had one tangential outlet duct rather than the two radial outlet ducts recommended in reference 2 but previous tests have shown that the change had no effect on over-all performance. The cast impeller was driven by a 1000-horsepower constant-speed induction motor through a magnetic coupling and two step-up gear boxes. The speed was varied by the magnetic coupling and regulated with an electronic control system.

The quantity of air flow through the unit was measured with a flat-plate orifice at the inlet to the surge tank. The over-all pressure and temperature measurements were made at the locations recommended in reference 2. Air pressures were indicated by mercury and alcohol manometers and temperatures were measured with shielded iron-constantan thermocouples calibrated in a controlled-temperature liquid bath. The impeller speed was measured with an automatic counter and checked with a stroboscope and speed-strip device.

METHOD OF TESTING

Preliminary examination. - The impellers as received were visually examined and the external defects such as cracks, incomplete castings, and damages were noted. An X-ray examination of the impeller hub was made to disclose internal casting defects. Brinell hardness measurements were taken on the impeller front and rear faces with a standard Brinell hardness tester (500-kg load, 10-mm-diameter steel ball), unless otherwise noted.

Physical-property tests. - As a strength check, an impeller of alloy 1, which was later performance-tested, was spun in the spin rig to a tip speed of 1320 feet per second based on the impeller diameter of 10.8 inches. This speed was 10 percent greater than that anticipated for the performance test. The other 11 impellers were spun at several successively higher speeds to determine how the elongation varied with the speed; the tests were continued until each of the 11 impellers failed.

The test specimens used to obtain the physical properties of the material were cut from the fragments of the cast impellers after the impellers were spun to destruction. Porous or faulty areas of the impeller were avoided wherever possible in choosing these test specimens. Three 0.25-inch-diameter tensile-test specimens were made from each impeller according to the standards of the American Society for Metals. These standards were used because they provide for a specimen size that could conveniently be cut from the impeller fragments. The specimens were X-rayed to determine the relative amount of porosity and to detect other defects. The specimens were tested in a standard tensile-testing machine to determine their tensile strength, elongation, and reduction in area.

A radial cross section was cut from the fragments of the hub of each impeller. Brinell hardness measurements were made over the surface of these sections to investigate the hardness distribution in both axial and radial directions and to detect any porous areas.

The structure of the alloys was metallographically examined in specimens cut from the fragments of the impellers. Photomicrographs were made at a magnification of 500 diameters and porosity examinations of alloy 1 were made at a magnification of 100 diameters.

Performance tests. - The performance tests of the cast impeller and the machined impeller were made according to the recommendations of reference 3 in an NACA variable-component supercharger test rig. The cast impeller was tested for the complete flow range at constant inlet Mach number (reference 4) and Reynolds number. The inlet static pressure was held constant at 20 inches of mercury absolute and the equivalent impeller tip speed was varied from 700 to 1200 feet per second in increments of 100 feet per second. The actual impeller tip speeds were corrected for inlet temperature on the basis of NACA sea-level temperature (518.4° R). The inlet total temperature varied during these tests from 95° to 104° F.

The Langley Field tests of the machined impeller were made at a constant discharge pressure of 40 inches of mercury absolute and actual tip speeds of 700 to 1200 feet per second in increments of 100 feet per second. This impeller failed at an impeller tip speed of 1300 feet per second, which terminated the tests.

RESULTS AND DISCUSSION

Preliminary Examination

Visual examination. - The impellers cast from alloy 1 had fewer obvious faults like porosity and blowholes, though the impellers cast from alloy 2 had a smoother finish and were more complete castings than those of alloy 1. These external qualities of the castings made from alloy 2 might be attributed to the silicon content, which increases the fluidity of the metal at the pouring temperature or to the casting technique. Blowholes and shrinkage cracks were visible through the bore section of several impellers of alloy 2. The castings made with alloy 1 appeared to have chilled too rapidly in the thin sections of the impeller, causing some of the blade tips to be incomplete. Results of the visual examination of the impellers are given in table I. The 12 impellers are designated by a double number, the aluminum-base alloy followed by the Navy serial number of the castings.

X-ray examination. - The X-ray examinations disclosed that only one of the six impellers of alloy 2 and five of the six impellers of alloy 1 could be considered satisfactory with regard to the internal quality of the castings. The X-ray photographs in figure 3 illustrate a satisfactory and an unsatisfactory hub of an impeller of each alloy. The best impeller of alloy 2 (2-23) had a slight amount of micro-shrinkage although the predominant defects of this series of castings were large shrinkage cracks and blowholes. Impeller 1-15, which had shrinkage cracks in the hub, was the only impeller of this alloy that had serious defects as shown by X-ray examination. Some of the impellers of alloy 1 had a slight amount of gas porosity, concentrated mostly in the impeller blades.

Brinell-hardness determinations. - The Brinell-hardness determinations made on the front and the rear faces of the impellers were found to be higher for alloy 2 and lower for alloy 1 than the values given in reference 5. In general, alloy 2 was harder than alloy 1. The results of all preliminary examinations are given in table I.

Physical Properties

Spin tests. - Impellers 2-9, 2-22, and 2-24 had serious internal defects, as shown by X-ray examination (table I) and, consequently, broke at rather low tip speeds of 930 to 950 feet per second. Impellers 2-A and 2-6 had fewer internal defects than the forementioned impellers and broke at tip speeds near 1080 feet per second. The best impeller of alloy 2 (2-23) had few internal defects and broke at the highest tip speed, 1184 feet per second.

Impeller 1-15, which had shrinkage cracks in the hub as shown in figure 3(c), began to fail at a tip speed of 1475 feet per second. This impeller was not spun to destruction because radial cracks from the impeller hub were noted when the rig was shut down to measure the impeller elongation. Impeller 1-25, which had some porosity near the rear face of the impeller, and impeller 1-13, which had a fine microscopic porosity throughout, burst at tip speeds of 1641 and 1663 feet per second, respectively. Impellers 1-11 and 1-14, which were the soundest impellers of alloy 1 spin-tested, burst at tip speeds in excess of 1700 feet per second. Surface particles of impellers 1-11 and 1-14 broke loose from the impellers at tip speeds of approximately 1700 feet per second, just before bursting. The bursting speeds of the impellers are listed in table II. A comparison of tables I and II shows that the bursting speed of an impeller of any one alloy is dependent to a large extent on the nature and extent of the internal defects, which may be obtained from X-ray examination.

All of the impellers except 1-15, which was not spun to destruction, failed through the hub. Usually the impellers burst into three parts, by splitting into halves with one of the halves further dividing into two parts. Figure 4 shows a typical fragment of cast impeller 1-11 after being spun to destruction. The roughness of the fracture indicates the porosity.

During the spin tests, the impellers were work-hardened by being highly stressed, as indicated by the measured permanent set. Work-hardening will change the physical characteristics of the material by increasing its tensile strength and Brinell hardness.

Tensile-strength tests and X-ray examination of bar specimens. - A comparison of X-ray photographs of tensile-test specimens cut from fragments of impellers 2-22 and 2-23 (figs. 5(a) and 5(b)) with the results of the tensile tests shown in table III demonstrates that the tensile strength varies indirectly with the amount of porosity indicated by X-ray examination. The strength of the tensile-test specimens from impellers of alloy 2 varied from a maximum of approximately 110 percent to about 30 percent of the tensile strength recommended in Navy specifications. The tensile-test results of alloy 2 were erratic because of variations in the extent of porosity and other faults among the test specimens as shown in the X-ray of figures 5(a) and 5(b). The average tensile strength of all tested specimens of this alloy was 20,900 pounds per square inch.

X-ray photographs of tensile-test specimens cut from fragments of impellers 1-11 and 1-25 are shown in figures 5(c) and 5(d). These representative X-rays show that a fine porosity exists in the specimens of alloy 1, which results in tensile strengths varying from a maximum of approximately 70 percent to 26 percent of the tensile strengths recommended in Navy specifications, except for one specimen that broke under the initial load of the testing machine. The tensile strengths of these specimens of alloy 1 are given in table III. The average tensile strength of all specimens of alloy 1 was 23,260 pounds per square inch. The results of the tensile tests of specimens taken from the impellers of both alloys indicated that the material was brittle.

The elongation of the specimens cut from cast impellers of both alloys was less than the elongation specified by the Navy. The elongation of specimens of alloy 2 was too small to be measured (Navy specification, 5 percent elongation) and that of the specimens of alloy 1 was a maximum of 4.5 percent (less than 40 percent of the specified elongation).

The results of these tensile-strength tests and the X-ray examinations show that the properties of the castings generally are nonuniform both within each impeller and also among the impellers of the same alloy.

Internal Brinell hardness. - The average internal Brinell hardness values for the alloys of the cast impellers and the recommended values of reference 5 for these alloys are given in table III. The average hardness values of specimens of the cast impellers of alloy 1 were fairly uniform but below the normal value given in reference 5; whereas the average hardnesses of alloy 2 were less uniform and above the normal value of reference 5. The individual hardness readings of each test specimen for the various impellers were fairly uniform except over porous areas and inclusions.

Metallurgical examination. - Specimens similar to those used for the internal Brinell hardness determinations were macroetched to examine the grain structure of the cast impellers. The macroetched specimens from typical impellers (1-13 and 2-9) are shown in figure 6. The specimen from impeller 1-13 shows a granular grain structure, porosity, and evidence of segregation, all of which would reduce the physical strength of the impeller. (The tensile strength was less than 70 percent of Navy specifications.) The specimen from impeller 2-9 shows porosity, blowholes, and shrinkage cracks and the grain structure was somewhat dendritic.

The structure of the alloys was further examined from photomicrographs of specimens cut from various portions of the cast impellers. A typical photomicrograph of a specimen of alloy 2 is shown in figure 7(a). The photomicrograph of the specimen showed that aluminum combined with impurties to form Al-Mn and complex compounds of Al-Fe-Si. The free silicon that came out of solution on cooling appears to be fairly uniformly distributed. The photomicrograph in figure 7(b) is of a specimen taken from the top of impeller 1-11 and shows complex compounds of Al-Fe-Mn-Co-Si and Mg_2Si and Al_2O_3. The fine porosity characteristic of this alloy is shown for impeller 1-11 at a magnification of 500 diameters in figure 7(b) and for impeller 1-15 at a magnification of 100 diameters in figure 8. The solid black areas indicate porosity. In general, the photomicrographs show that the impellers are of the normal structure with the maximum permissible amount of impurities.

Performance Tests

Because of difficulties in obtaining reliable data at the impeller tip caused by the highly turbulent impeller-discharge air, the cast impeller (1-12) that was not spin-tested to destruction was tested in combination with a 34-inch vaneless diffuser and the performance was determined from measurements in the test-rig outlet duct. The performance of the cast impeller is compared with that of the machined impeller in figures 9 and 10. Neither the impellers nor the diffusers were geometrically the same and the method of testing was somewhat different for the two combinations. The essential difference in the testing methods was that the Reynolds number and corrected tip speeds $U/\sqrt{\theta}$ of the two units were slightly different. Test results show that the effect of Reynolds number is small at low Mach numbers; hence, the combined effect of the geometric and impeller surface differences can be adequately determined by performance comparison. Differences in test setup and facilities permitted operation of the cast impeller with the vaneless diffuser at a lower pressure ratio P_2/P_1 than the machined impeller. This difference in minimum pressure ratios at maximum flows prevents a comparison of range at tip speeds of 700 and 800 feet per second but at all the higher tip speeds the machined impeller handled a larger corrected volume of air $Q_{1t}/\sqrt{\theta}$ than the cast impeller (fig. 9). The difference in the maximum flows handled is probably due to the smaller passage area of the cast impeller, which causes critical air velocities (hence choking effects) through the passages of the cast impeller at lower flows than through the machined impeller passages at comparable tip speeds. The machined impeller was also able to operate at lower flows than the cast impeller at all comparable tip speeds except 700 feet per second. For the test on the machined impeller with the diffuser at this speed, however, operation was apparently halted before final surge had been reached. The greater surface roughness and possible warping of the cast impeller probably led to early separation and consequent surge at higher flows than in the machined-impeller combination.

The over-all peak adiabatic efficiency η_{ad}, pressure coefficient q_{ad}, and pressure ratio P_2/P_1 of the two impeller-diffuser combinations are shown in figure 10. The peak adiabatic efficiency of the cast impeller with the diffuser was approximately 78 and 62 percent at corrected tip speeds of 700 and 1200 feet per second, respectively; these efficiencies were approximately 3 points lower than the corresponding peak efficiency of the machined impeller with the diffuser at low speeds and 2 points lower at high speeds. The peak pressure coefficient was approximately 63 percent for both impeller-diffuser combinations at a corrected tip speed of 700 feet per second. The peak pressure coefficient of the cast-impeller combination was slightly lower than that of the machined-impeller combination at all tip speeds above 700 feet per second; at 1200 feet per second, it was 53 percent. The peak pressure ratio of the cast impeller with the vaneless diffuser was slightly lower than that of the machined impeller with the vaneless diffuser at all corrected tip speeds. A maximum pressure ratio of 2.16 was obtained with the cast-impeller combination at a corrected tip speed of 1200 feet per second.

Although the diffuser used with the cast impeller was designed to improve the performance of this combination, results of these tests (figs. 9 and 10) showed a decrease in over-all performance compared with that of the machined-impeller combination. Most of this decrease in performance can be attributed to the differences in the impellers and is probably due to the effects of the rough casting surface and distortion of the impeller passages during casting and heat-treating.

The effects of elevated temperature and vibrations on the suitability of cast impellers were not investigated. During the performance tests, however, the air-discharge temperature reached 400° F without any noticeable effect on the strength of the cast impeller; the impeller temperature, however, was somewhat lower than 400° F. Vibrations, such as those induced by the proximity of diffuser vanes in a vaned-diffuser installation, could cause fatigue failure of the impeller. Induced vibrations of this nature did not exist during either the spin or performance tests. The impeller has operated however, under surge conditions for extended periods of time with no apparent detrimental effects.

SUMMARY OF RESULTS

From physical tests of 12 cast impellers of alloys 1 and 2 and a comparison of the performance of the cast impeller and the machined impeller with vaneless diffusers, the following results were obtained:

1. Inasmuch as the impellers of the 1-alloy group cast by the "lost wax" process were successfully spin-tested to high tip speeds and one of them was performance-tested up to a corrected tip speed of 1200 feet per second, these impellers should be satisfactory for use in a supercharger up to at least this speed.

2. The adiabatic efficiency of the cast impeller with the vaneless diffuser was a maximum of 78 percent at a corrected tip speed of 700 feet per second and was 63 percent at a corrected tip speed of 1200 feet per second. These efficiencies were 3 and 2 points, respectively, lower than the corresponding peak efficiencies of the machined impeller with the vaneless diffuser at comparable speeds. At each speed tested, the performance of the cast-impeller combination was slightly lower than that of the machined-impeller combination.

3. Although the X-ray examination of the hub of the impellers of alloy 2 showed that one of the six impellers might be considered satisfactory, all impellers of this alloy failed at tip speeds of 933 to 1184 feet per second.

4. The X-ray examination of the hub of the impellers of alloy 1 indicated that five of the six impellers might be considered satisfactory. The four satisfactory impellers that were spin-tested to destruction failed at extremely high tip speeds between 1641 to 1743 feet per second.

5. Tests of tensile-test specimens showed that impellers of both alloys were of approximately the same strength. Tensile-test specimens of impellers of alloy 1 and alloy 2 failed at a maximum of 70 and 110 percent of Navy specifications, respectively. The average tensile strength of all specimens tested was 20,900 for alloy 2 and 23,260 pounds per square inch for alloy 1.

6. Specimens of alloy 1 had a maximum elongation of $4\frac{1}{2}$ percent, which is approximately one-third of the elongation of Navy specifications, 12 percent. Tensile-strength tests of specimens of impellers of alloy 2 showed no measurable elongation, which indicates material of a brittle nature.

Aircraft Engine Research Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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TABLE I - PRELIMINARY EXAMINATION OF CAST ALUMINUM-ALLOY MIXED-FLOW IMPELLERS

Impeller (a)	Visual examination	X-ray examination	Average Brinell hardness	
			Front	Rear
1-11	Blades not full, undersized, crack in one blade tip	No internal defects.	71.6	69.8
1-12	Inlet blade tips undersized, slightly damaged	Slight amount of gas porosity in blades, hub good.	66.0	[b]54.0
1-13	Same as 1-12, one outlet blade tip bent	Gas porosity in blades, considerable mottling.	82.1	[b]42.6
1-14	Blades not cast full	Slight porosity.	72.2	66.0
1-15	Blade tips at inlet not cast full	Shrinkage cracks in hub, some porosity.	68.0	[b]52.0
1-25	Slight porosity at impeller rear, bore eccentric	No internal defects.	76.6	50.4
2-A	Slight porosity at impeller rear, one blade tip nicked, six blade tips broken off in machining	Some porosity and hot shortness.	90.8	83.0
2-6	Void in bore section, shrinkage and hot-shortness in bore, nine blade tips broken off in machining	Considerable porosity and shrinkage.	79.4	83.0
2-9	Shrinkage cracks in bore, leading edge of blade damaged in handling	Large shrinkage cracks in hub.	92.0	[b]78.0
2-22	Slight porosity, blades damaged slightly in handling	Considerable porosity, hot-shortness in outer hub, porosity and microshrinkage in bore.	72.4	77.4
2-23	Inlet blade tips slightly damaged, one blade tip broken off in machining	Slight microshrinkage.	91.2	86.8
2-24	Large porous areas and blowholes in bore, indication of excessive shrinkage	Shrinkage, hot-shortness, and some porosity from hub to outer bore.	94.0	81.3

[a]The first number is the aluminum - base alloy and the second is the Navy serial number of the casting.

[b]Vickers Brinell, 20-kg load and 2-mm steel ball; all other Brinell hardness determinations standard, 500-kg load and 10-mm steel ball.

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TABLE II - RESULTS OF SPIN TESTS OF CAST ALUMINUM-ALLOY

MIXED-FLOW IMPELLERS

Impeller	Maximum impeller diameter (in.)	Elongation (in.)	Highest tip speed at which elongation was measured (fps)	Speed at which impeller failed	
				(rpm)	(fps)
1-11	11.04	0.029	1711	35,520	1711
[a]1-12	10.89	.001	1320	--------	------
1-13	10.82	.009	1600	35,220	1663
1-14	11.09	.020	1702	36,000	1743
1-15	11.08	.018	1475	30,480	[b]1475
1-25	11.10	.0265	1633	33,900	1641
2-A	11.06	.000	1014	22,320	1077
2-6	11.02	.001	1010	22,560	1085
2-9	11.02	.004	800	19,200	933
2-22	11.04	----------	-----------	19,600	948
2-23	11.11	.000	1018	24,420	1184
2-24	11.05	----------	-----------	19,500	940

[a]Impeller was performance-tested.

[b]Impeller was not spun to bursting because radial cracks indicating failure were seen after it was spun to 1475 feet per second.

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TABLE III - PHYSICAL PROPERTIES OF CAST ALUMINUM-ALLOY MIXED-FLOW IMPELLERS FROM SPECIFICATIONS AND FROM NACA TESTS

Specifications

Alloy	Brinell hardness number	Tensile strength (lb/sq in.)	Elongation in 2-inch gage length (percent)
[a]1	----------------	42,000	12
[a]2	----------------	26,000	5
[b]1	78	38,000	12
[c]2	50-65	24,000	5-7

Test Results

Impeller	Average Brinell hardness number	Specimen	Tensile strength (lb/sq in.)	Elongation in 1-inch gage length (percent)
1-11	60	A	28,400	1.56
		B	22,900	1.56
		C	27,400	(d)
[e]1-12	------------	--------	------------	----------------
1-13	66.6	A	28,000	4.0
		B	25,000	3.3
		C	26,100	3.0
1-14	66.8	A	11,150	3.12
		B	28,750	1.56
		C	24,400	(d)
1-15	66.8	A	29,400	0
		B	25,400	0
		C	21,600	0
1-25	61.0	A	(f)	----------------
		B	23,000	4.5
		C	27,400	4.5
2-A	77.0	A	15,000	(d)
		B	17,350	(d)
		C	19,350	0
2-6	75.0	A	21,150	0
		B	21,700	0
		C	19,650	0
2-9	86.1	A	22,400	0
		B	22,650	0
		C	20,750	0
2-22	73.0	A	14,200	0
		B	22,000	0
		C	7,550	0
2-23	85.0	A	28,300	0
		B	29,400	0
		C	29,300	0
2-24	74.7	A	10,050	0
		B	27,400	0
		C	28,000	0

[a]Navy specifications.
[b]Reference 5, p. 1373; 10 percent Mg is same as alloy 1.
[c]Reference 5, p. 1384.
[d]Broke outside gage length.
[e]Impeller was performance-tested.
[f]Specimen broke under initial load.

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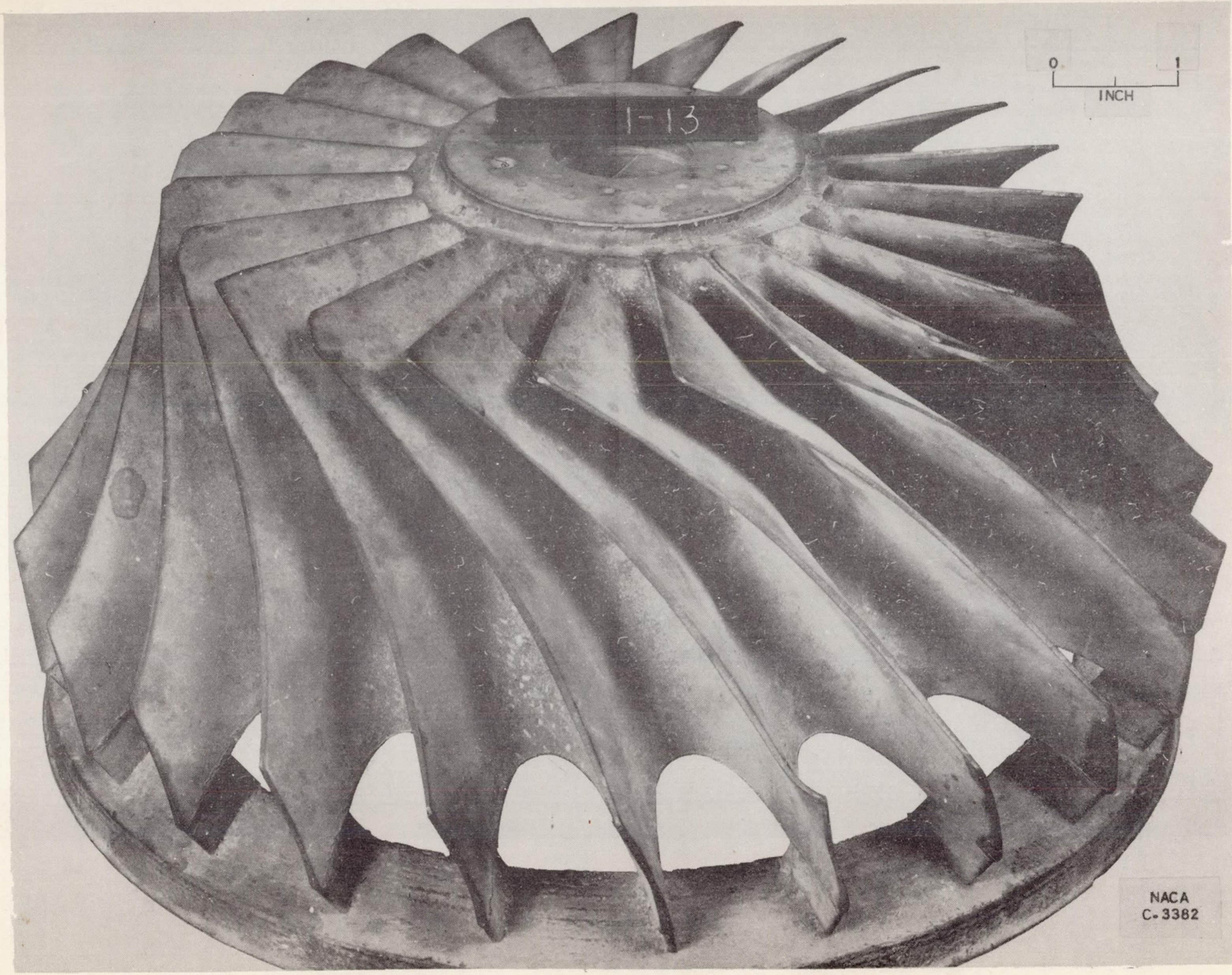

Figure 1. - Cast mixed-flow impeller received from the U.S. Naval Engineering Experiment station, Annapolis, Md.

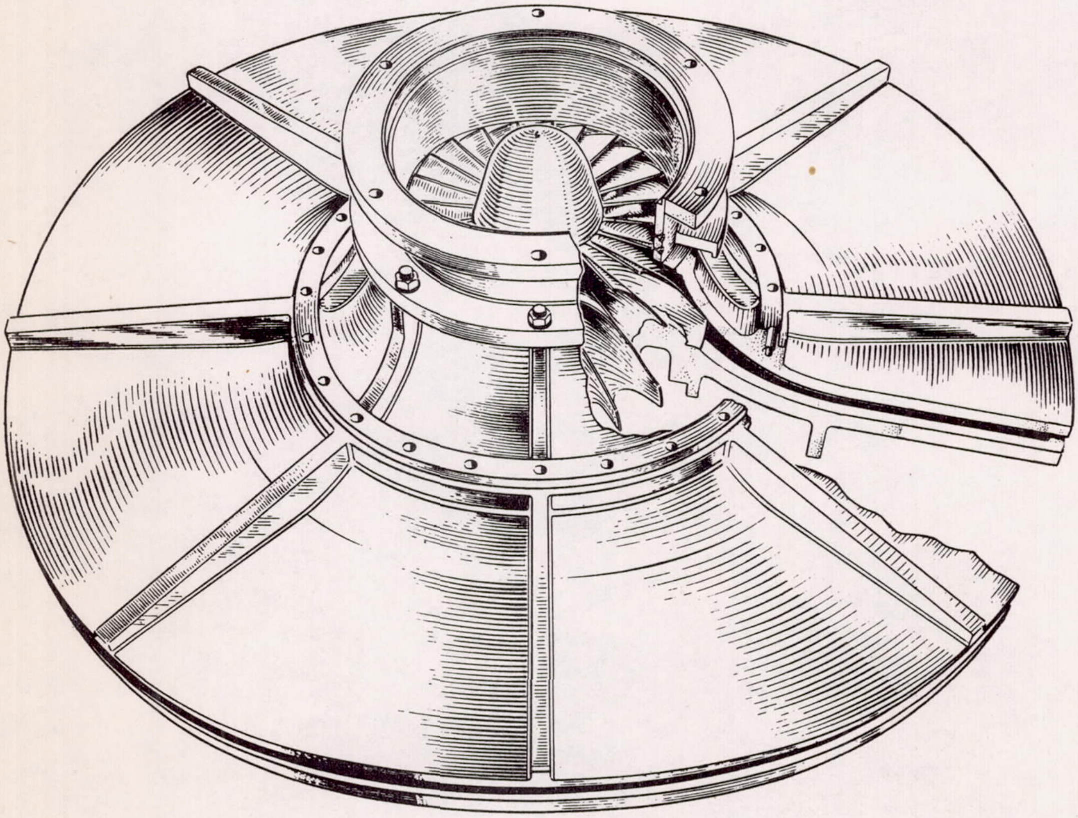

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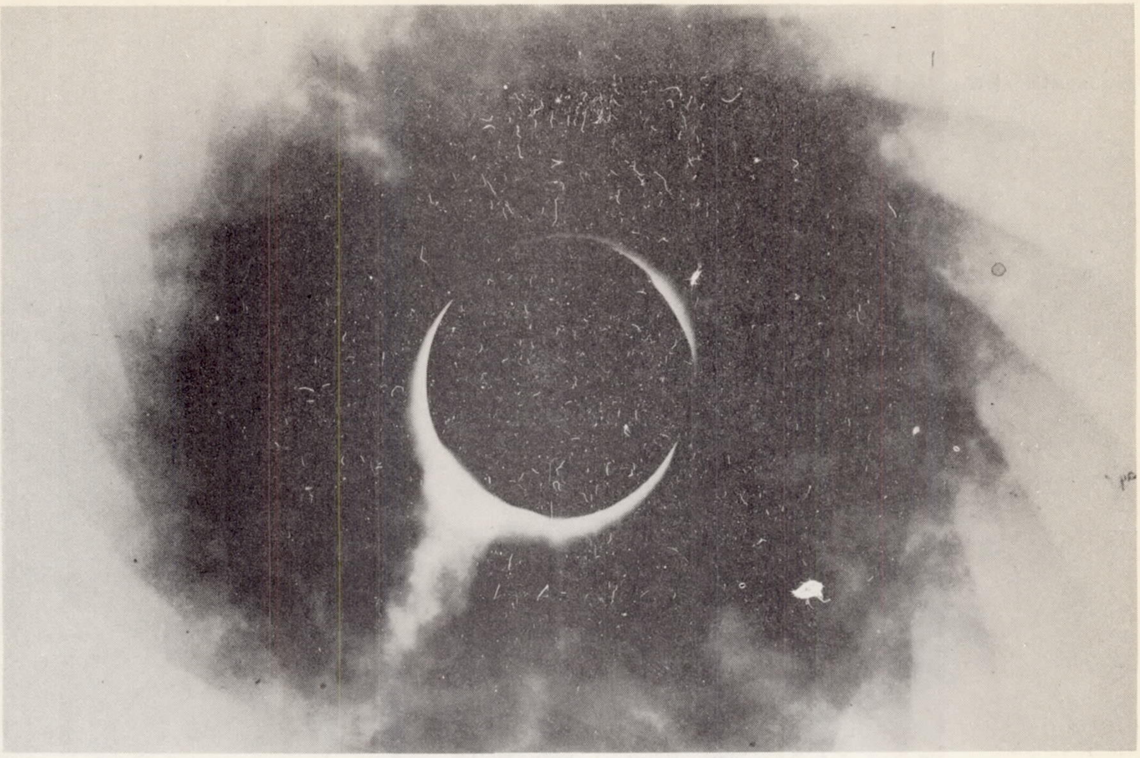
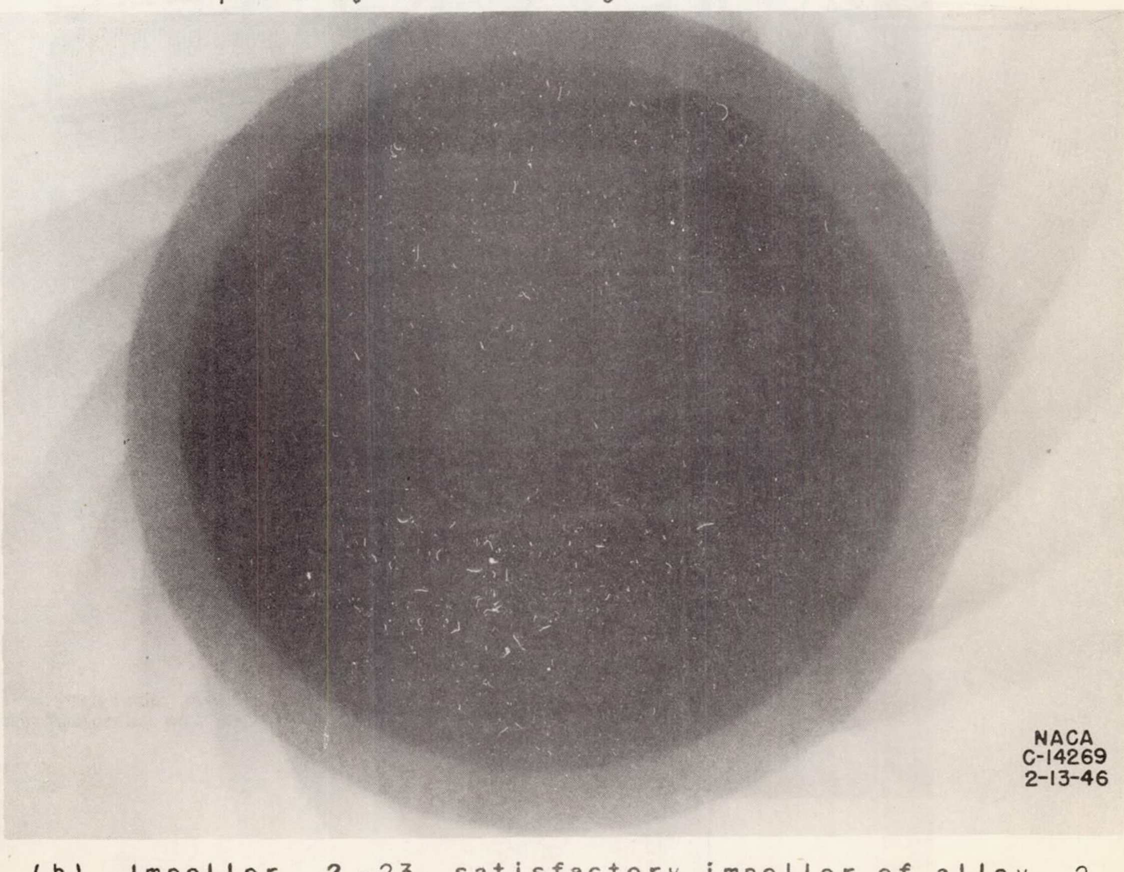
Figure 2. - Sketch of cast mixed-flow impeller with vaneless diffuser.

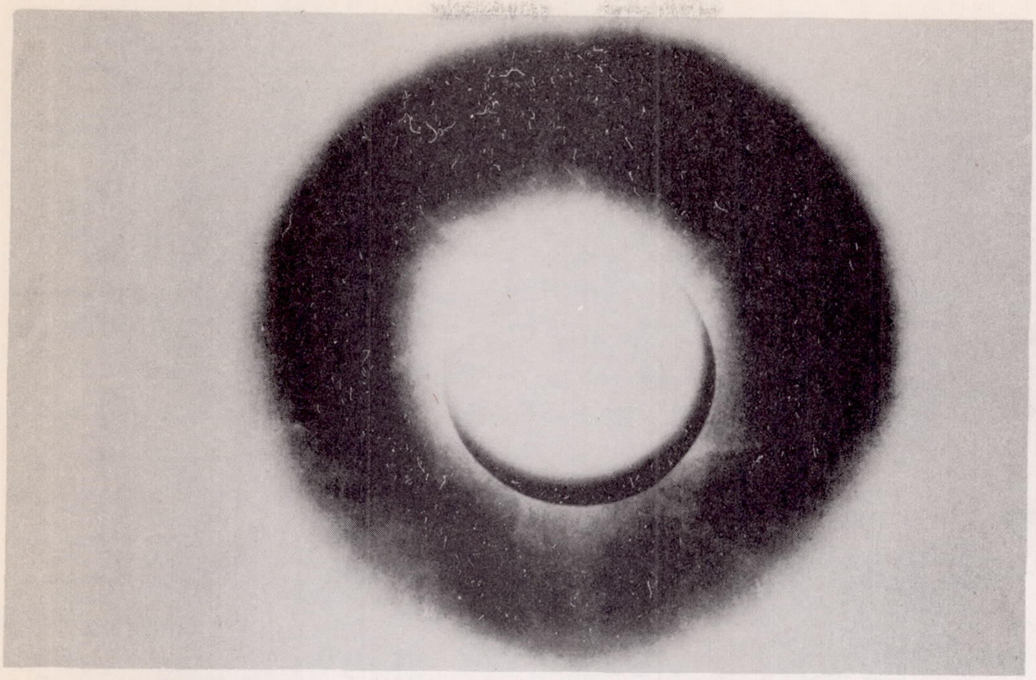


(a) Impeller 2-9, unsatisfactory impeller of alloy 2 with porosity and shrinkage cracks.

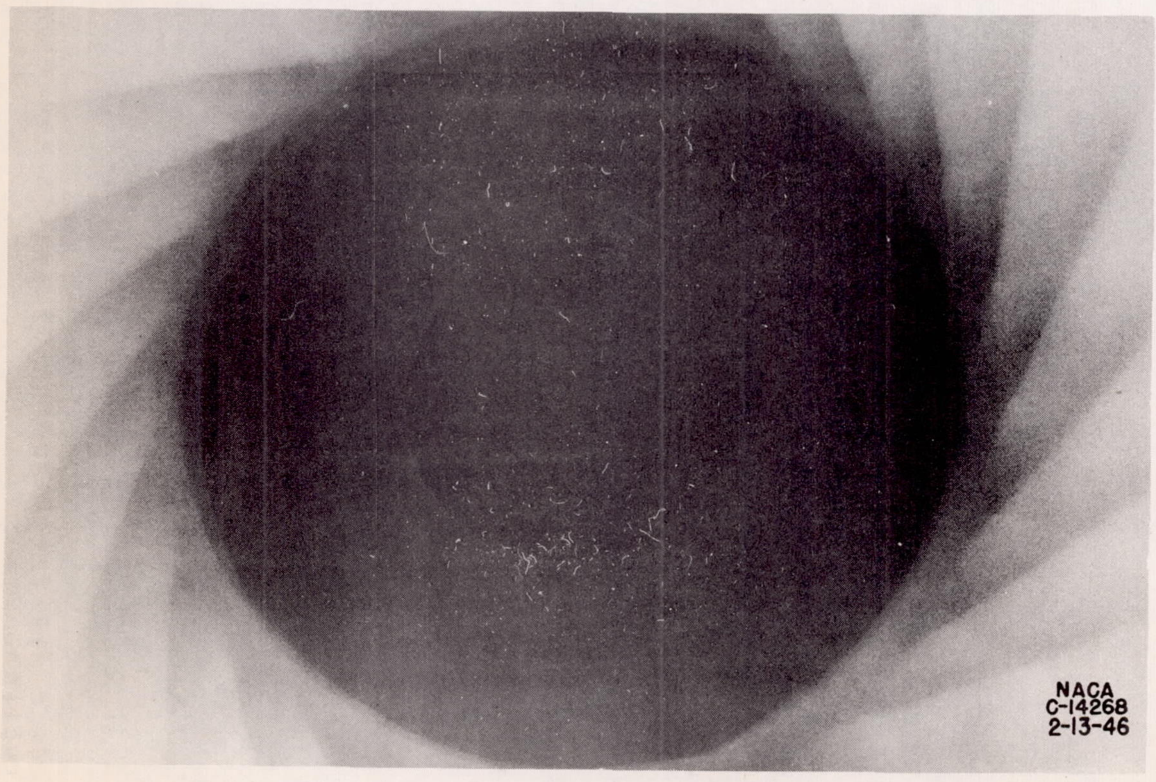


(b) Impeller 2-23, satisfactory impeller of alloy 2.

Figure 3. - X-rays of hub of cast mixed-flow impellers.



(c) Impeller I-15, unsatisfactory impeller of alloy I with shrinkage cracks.



(d) Impeller I-11, satisfactory impeller of alloy I.

Figure 3. - Concluded.

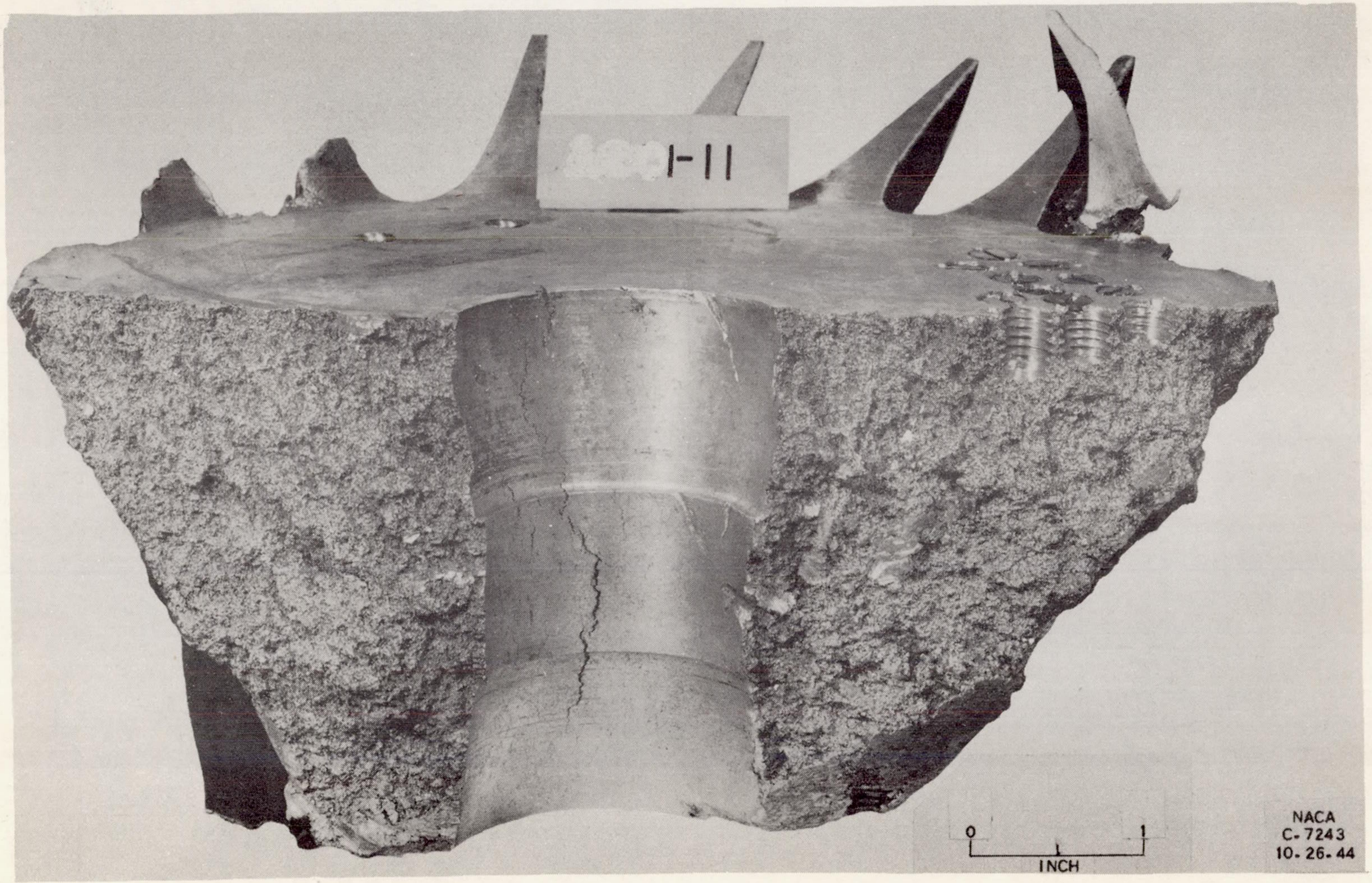
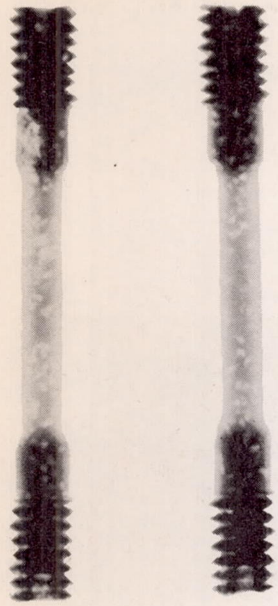


Figure 4. - Typical fragment of cast mixed-flow impeller I-11 after being spun to destruction.

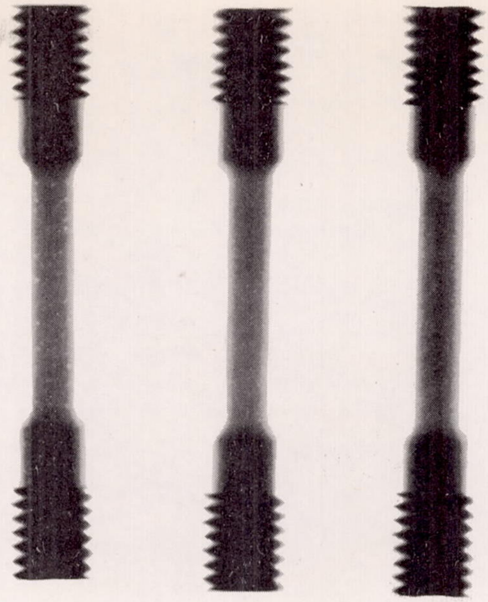
E-271

E-277



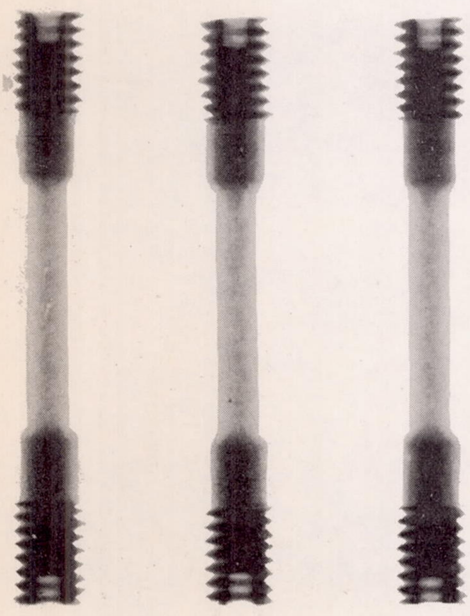
A B C

(a) Specimens from impeller 2 -22



A B C

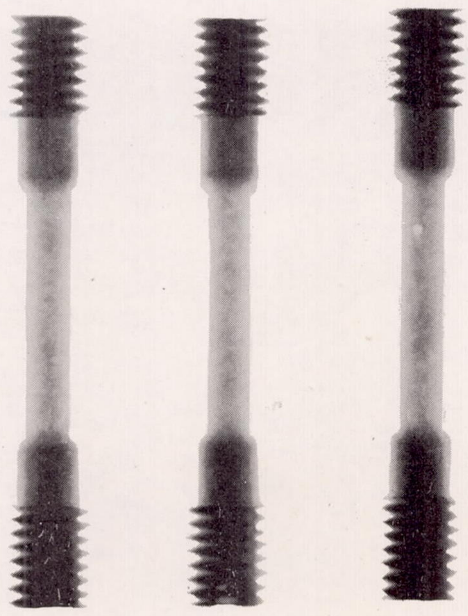
(b) Specimens from impeller 2 -23



A B C

(c) Specimens from impeller 1-11

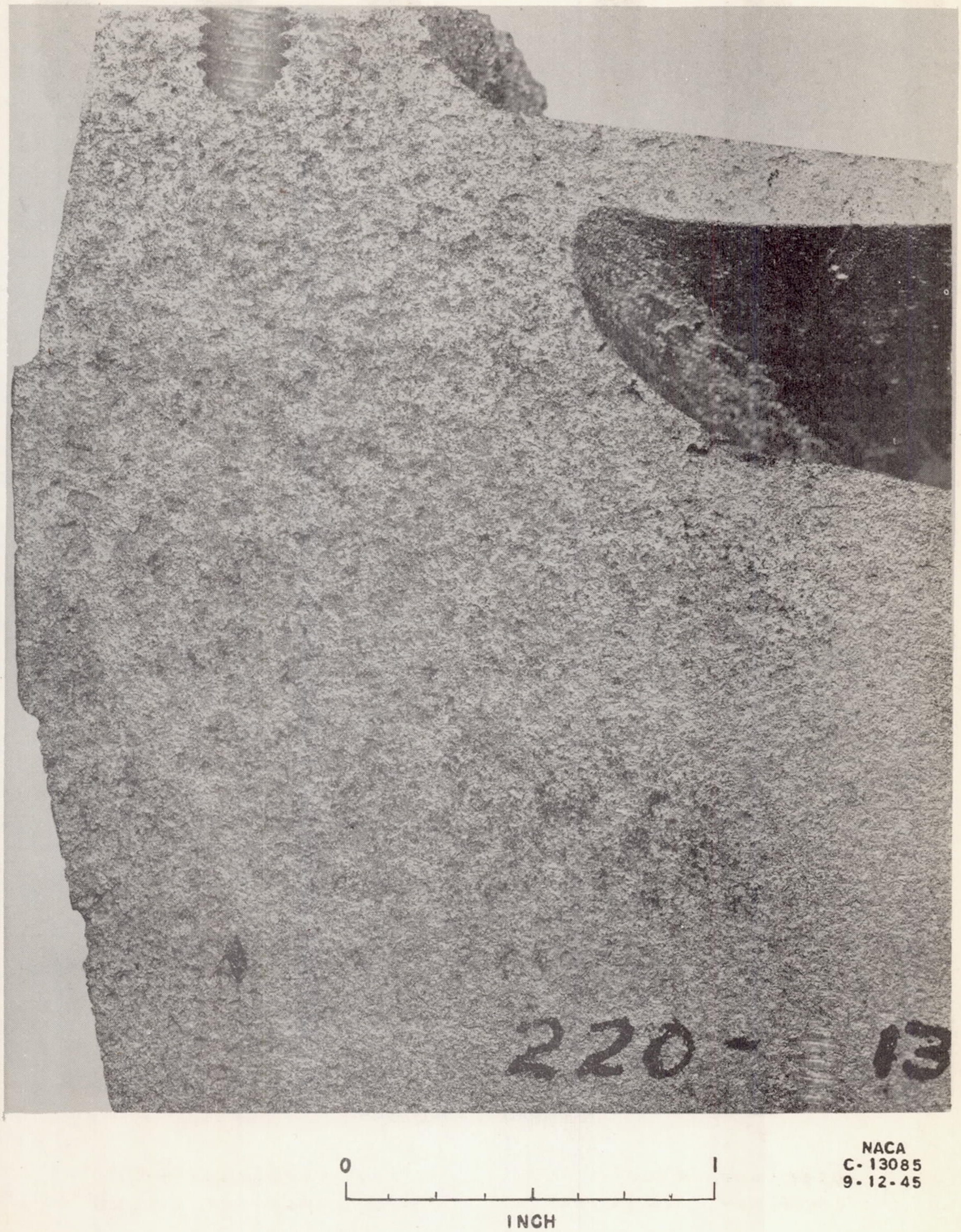
NACA
C-14270
2-13-46



A B C

(d) Specimens from impeller 1-25

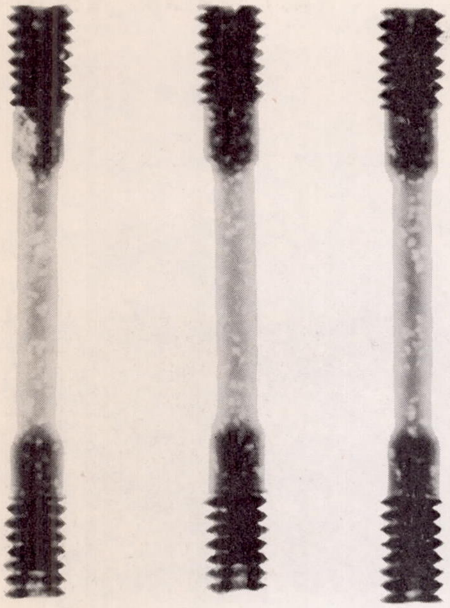
Figure 5. - X-ray photographs of tensile-test specimens cut from fragments of cast mixed-flow impellers.



(a) Impeller 1-13.

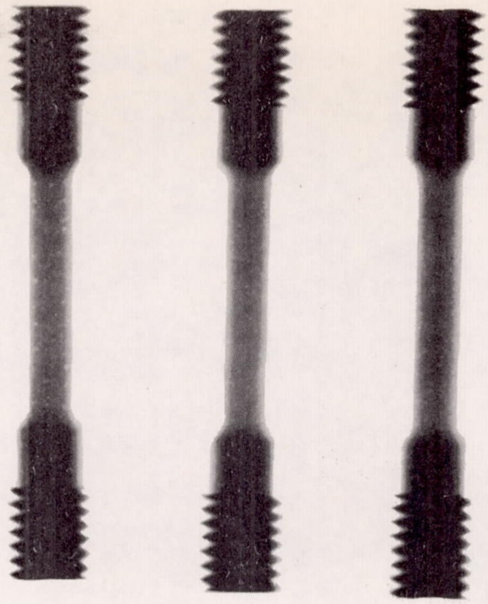
Figure 6. - Specimens cut from the cast mixed-flow impellers macroetched to show grain structure. X2.25.

E-277



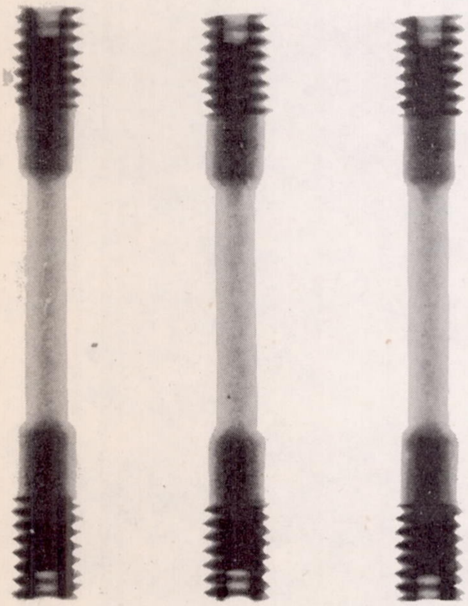
A B C

(a) Specimens from impeller 2-22



A B C

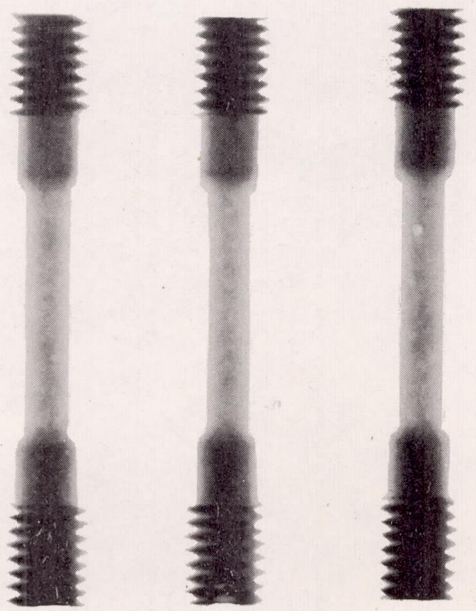
(b) Specimens from impeller 2-23



A B C

(c) Specimens from impeller 1-11

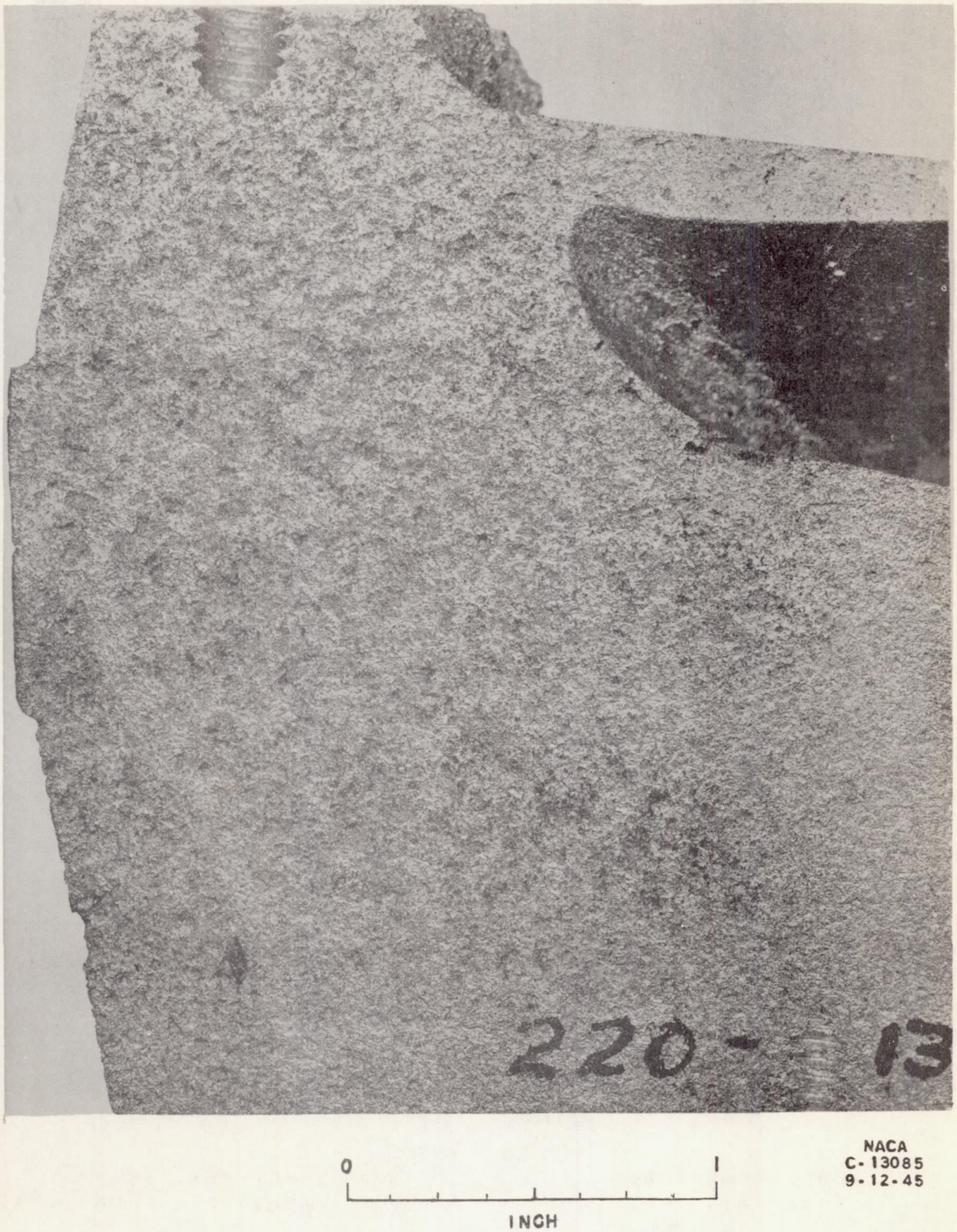
NACA
C-14270
2-13-46



A B C

(d) Specimens from impeller 1-25

Figure 5. - X-ray photographs of tensile-test specimens cut from fragments of cast mixed-flow impellers.



NACA
C-13085
9-12-45

(a) Impeller 1-13.

Figure 6. - Specimens cut from the cast mixed-flow impellers macroetched to show grain structure. X2.25.

0 — 1

INCH

NACA
C-13084
9-12-45

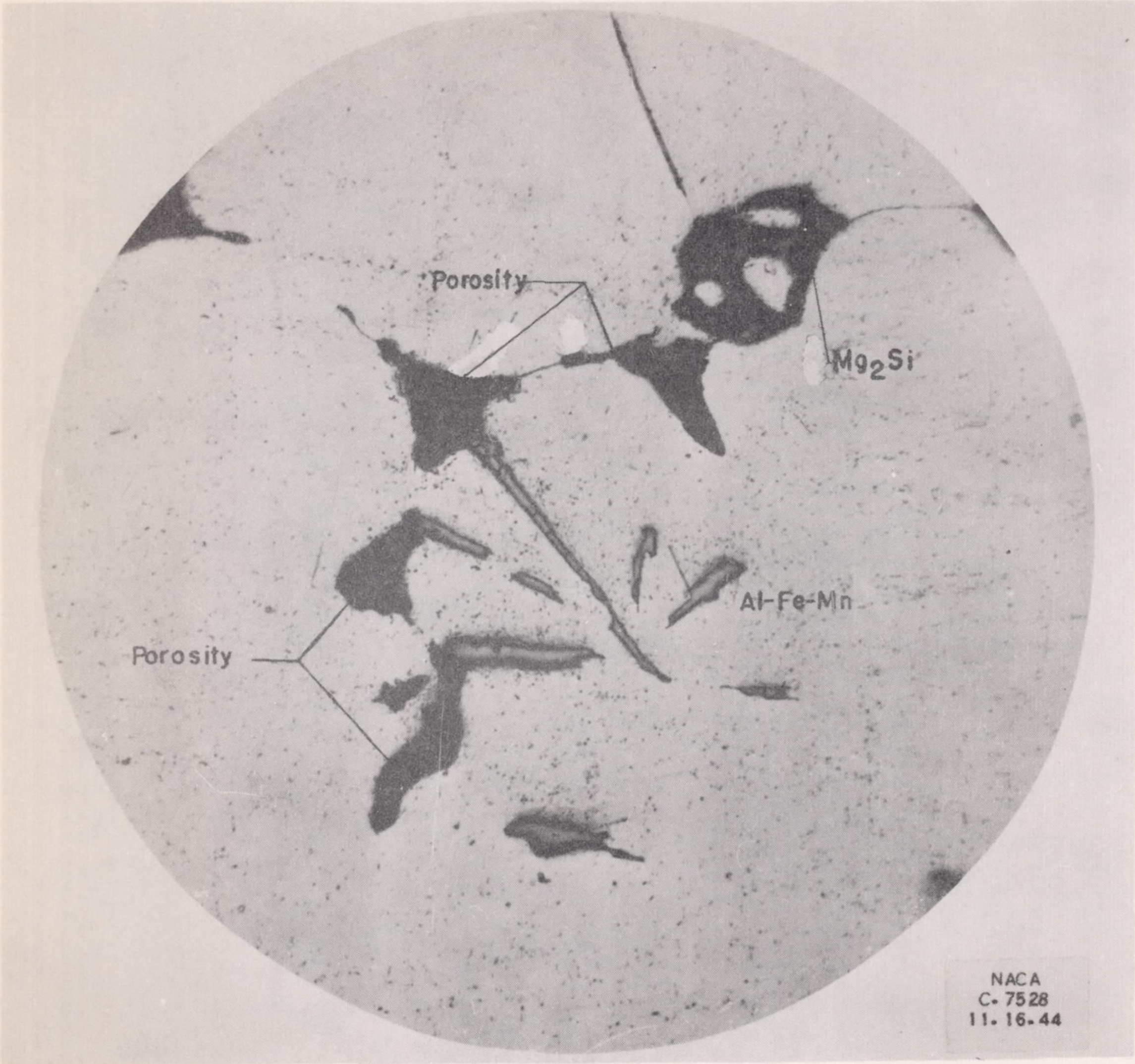
(b) Impeller 2-9.

Figure 6. - Concluded.

E277

(a) From top of impeller 2-23. Etched in hydrofluoric acid.

Figure 7. - Etched specimens cut from various impellers showing porosity. X500.



(b) From top of impeller I-11. Etched in mixed acid.

Figure 7. - Concluded.

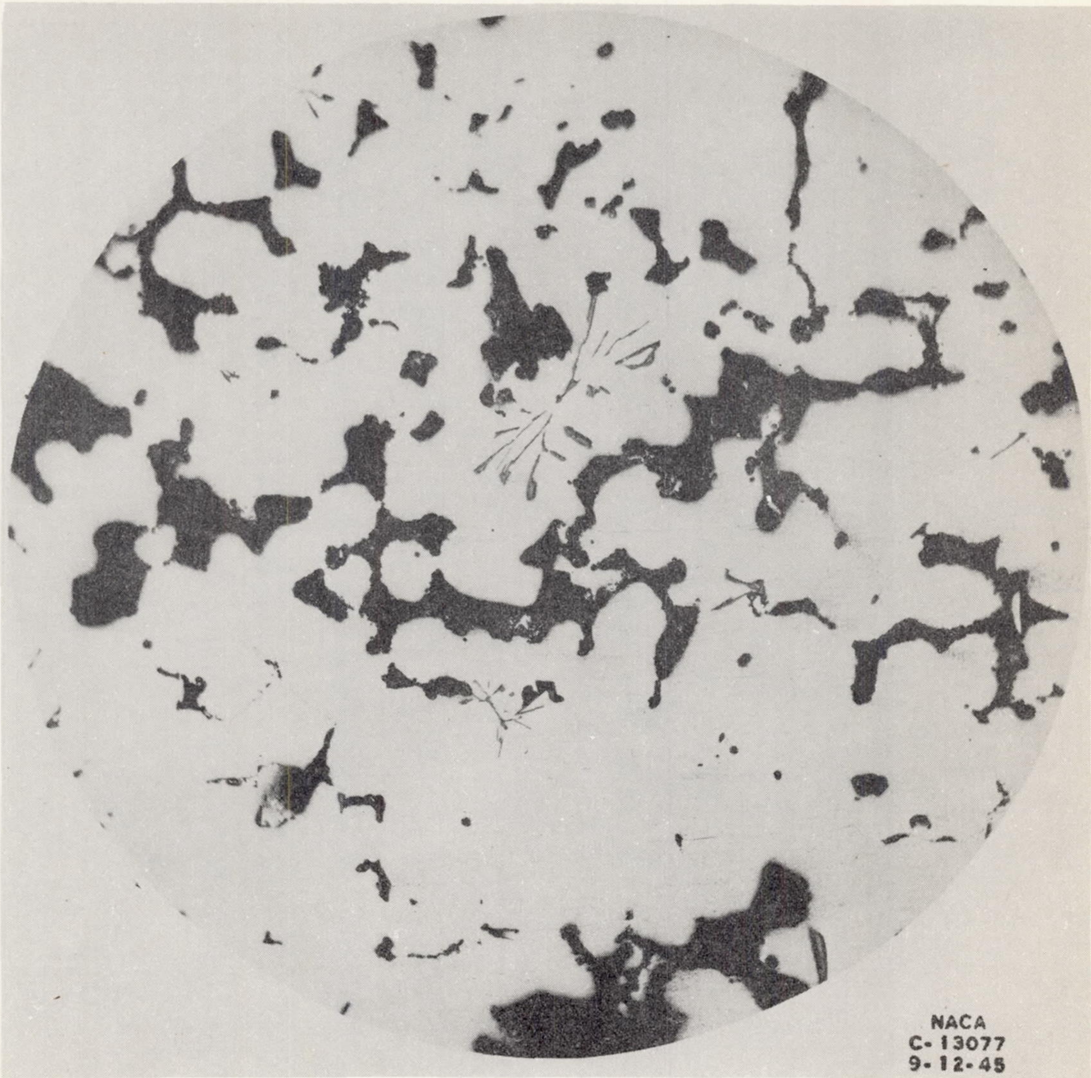
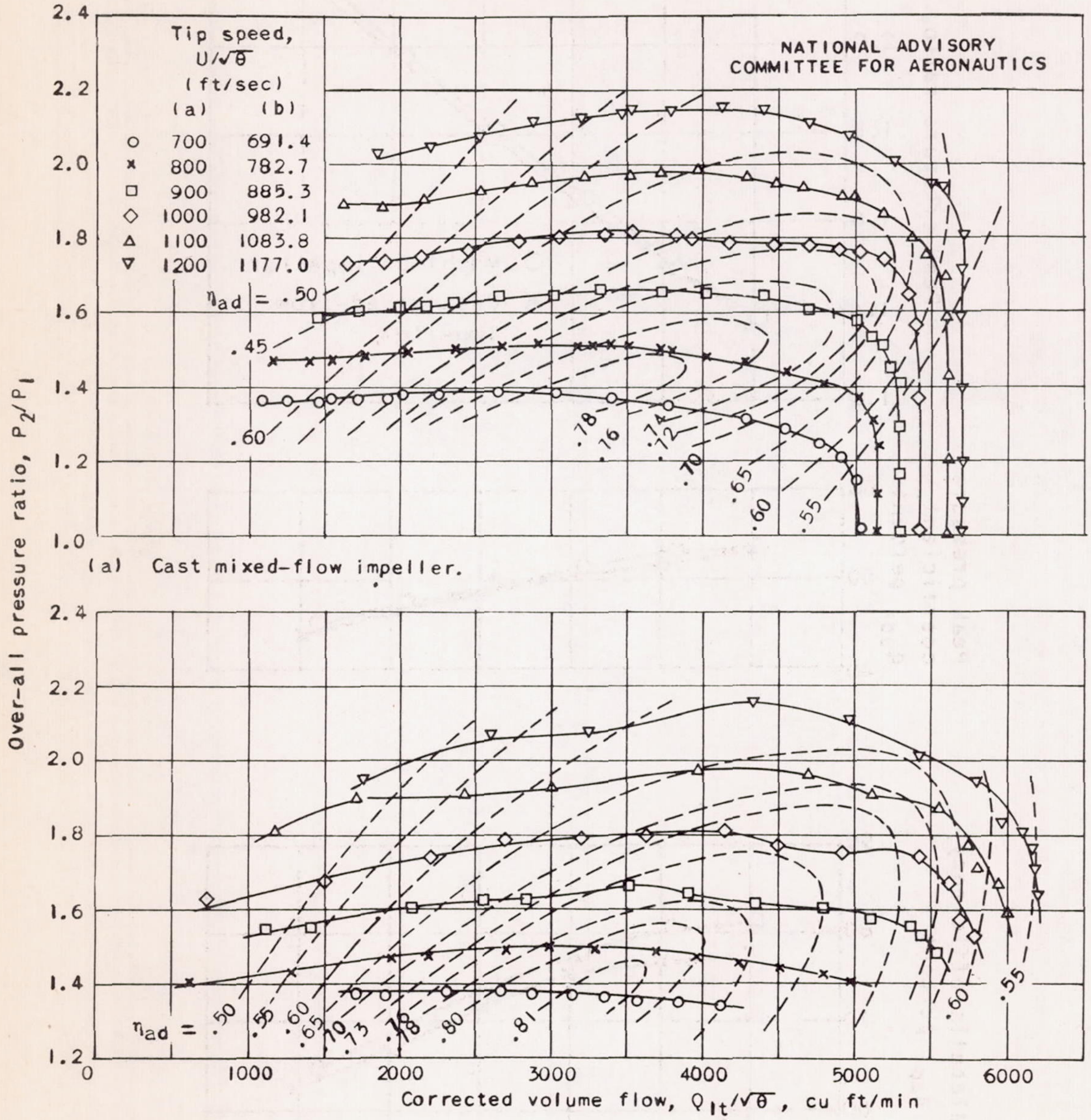


Figure 8. - Etched specimen from bottom of impeller 1-15 showing characteristic porosity of the alloy. Etched in mixed acid. X100.

E277



(b) Machined impeller.

Figure 9. - Over-all pressure ratio and corrected volume flow with over-all adiabatic efficiency of impellers with NACA vaneless diffuser.

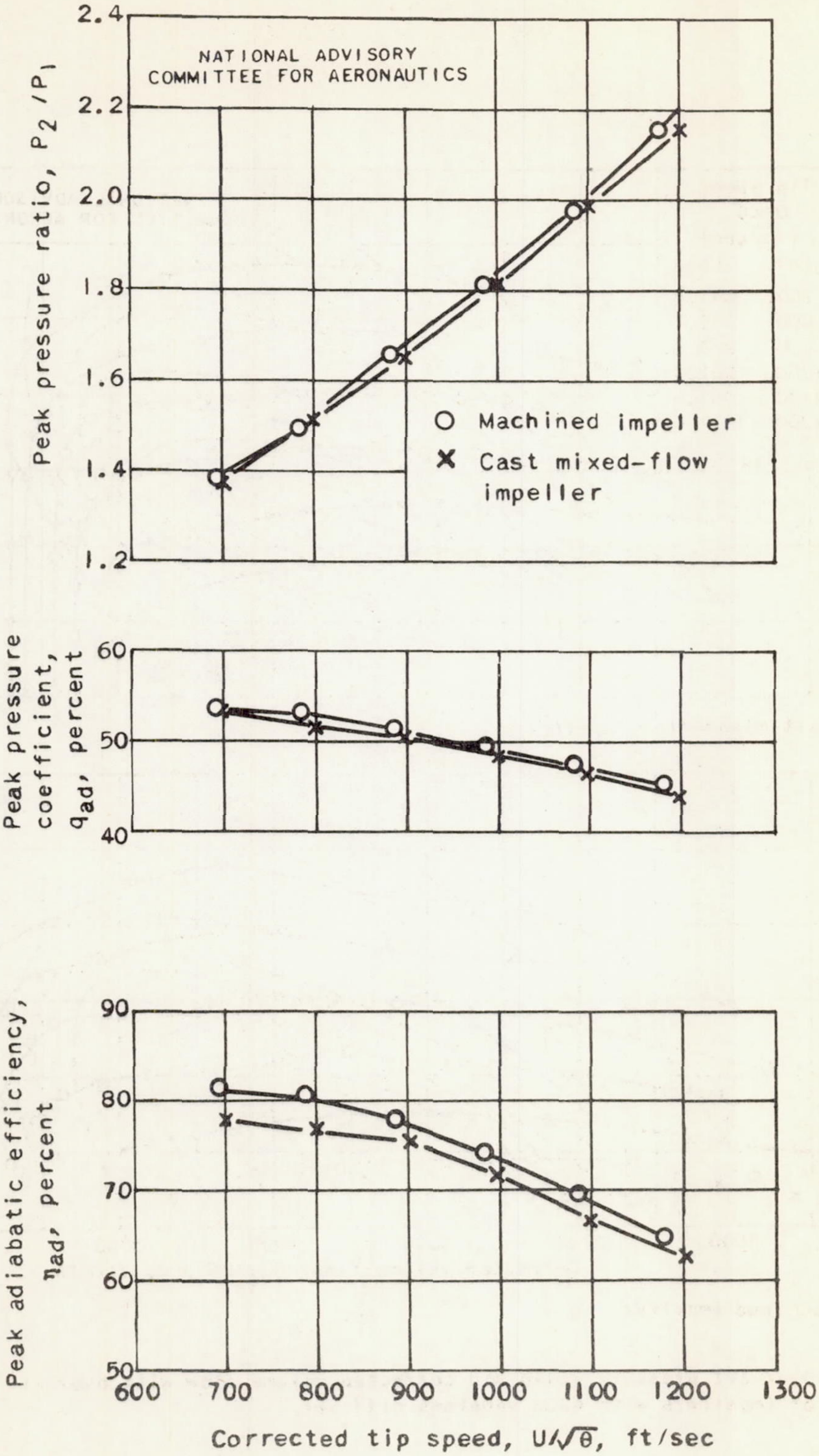


Figure 10. - Over-all peak performance of impellers with NACA vaneless diffuser.