

RESEARCH MEMORANDUM

RESULTS OF TURBOJET ENGINE OPERATION TESTS USING
A 50-50 MIXTURE OF JP-4 AND TRIBUTYL BORATE
AS THE FUEL

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON

January 16, 1957
Declassified October 31, 1958

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An experimental investigation was conducted on a centrifugal-type turbojet engine using a 50-50 mixture of tributyl borate and JP-4 fuel as the fuel. This fuel mixture is not a high-energy fuel but it forms boric oxide as one of the products of combustion. The boric oxide formed with this fuel mixture is one-thirteenth as great as that which would be formed with high-energy fuels. This fuel mixture was used to determine the locations in an engine where boric oxide deposits would form and the relative magnitude of the deposits formed in different engine locations. The effect of the deposits on the engine performance was also determined. The greatest deposits of boric oxide formed in the combustor domes. Thin deposits formed on the combustor walls and on the turbine rotor and stator blades. The engine was operated for $1\frac{1}{2}$ hours with this fuel mixture and during this time the deposits that formed in the engine had no effect on the engine thrust.

INTRODUCTION

Improvements in the specific fuel consumption and hence airplane range can be realized if fuels having heats of combustion higher than present hydrocarbon fuels are used in jet engines. The high-energy fuels which offer the greatest gains are diborane, pentaborane, and boron. One characteristic of high-energy fuels is the presence of solid oxides of the fuels in the products of combustion (boric oxide for the case of the above fuels). Because boric oxide has a low melting point, the oxide occurs as a liquid in the products of combustion until it is solidified by coming in contact with a relatively cool engine part. By this process deposits will form in an engine. These deposits may affect the engine performance and make a redesign of some of the engine components necessary so that these deposits will not accumulate in the engine. The magnitude of the deposits, their locations in the engine, and their effect on engine performance must be determined before engine design changes can be effected to permit the use of the high-energy fuels. An experimental investigation on a centrifugal-type turbojet

engine has been made at the NACA Lewis laboratory to evaluate these factors. The fuel used was a 50-50 mixture of tributyl borate and JP-4 fuel because high-energy fuels were not available in sufficient quantity for this investigation. The fuel mixture used produced one-thirteenth the quantity of boric oxide in the products of combustion as the high-energy fuels. For this reason the magnitudes of the deposits of boric oxide that form in the different engine locations must be considered relative, but the locations where the deposits form will be the same as they would be with high-energy fuels.

APPARATUS

A standard production J33 turbojet engine was used in this investigation. Instrumentation was provided for the measurement of engine thrust, speed, fuel consumption, and exhaust-gas temperature. A 50-50 mixture by weight of JP-4 fuel and tributyl borate was used as the fuel. This mixture is not a high-energy fuel but it does form boric oxide upon combustion. The mixture does not produce as large an amount of B_2O_3 as the high-energy fuels but it will give an indication of the locations, the quantity, and the characteristics of the deposits formed in the engine. The 50-50 mixture of JP-4 and tributyl borate produces 1 pound of boric oxide for 13 pounds of the mixture while 1 pound of high-energy fuel such as trimethyl diborane will produce 1 pound of boric oxide.

TEST PROCEDURE

The engine was operated first with JP-4 fuel only, so that the standard performance of this engine could be determined for comparison with the data that were to be obtained with the special fuel mixture. The engine was then operated at a constant engine speed of 11,500 rpm with the 50-50 fuel mixture of JP-4 and tributyl borate. Engine data were taken at 10-minute intervals so that any change in the engine performance caused by the formation of deposits of boric oxide on the engine parts could be detected. The quantity of tributyl borate that was available for these tests limited the total engine operating time to $1\frac{1}{2}$ hours, of which 1 hour and 12 minutes was at the rated engine speed of 11,500 rpm. After the engine was operated with the special fuel mixture it was disassembled and the various parts with which the combustion gas came in contact were inspected for deposits of boric oxide.

RESULTS AND DISCUSSION

Boric Oxide Deposits Formed in Engine

Photographs of various engine parts as they appeared after $1\frac{1}{2}$ hours of engine operation with the 50-50 mixture of JP-4 and tributyl borate

as the fuel are shown in figures 1 through 7. The deposits of boric oxide in the engine were white, hard, and crystalline.

Three fuel nozzles assembled in their burner domes are shown in figure 1. The deposits in these parts were thicker than in any others. The deposits were heaviest on the fuel nozzles and on the air spinner disk which fits around the fuel nozzles. It is conceivable that the deposit on the fuel nozzles could build up to such a degree that it would alter the shape of the cone of the fuel spray and thus reduce the combustion efficiency. Besides having the boric oxide deposit on the outside, several of the fuel nozzles were completely plugged. This was probably a result of the fuel left in the nozzles hydrolyzing after the engine was shut down. This is a characteristic of the high-energy fuels also, and is a disadvantage that must be considered. The build-up of boric oxide on the air spinner disk was very heavy also. The vanes in the spinner were almost completely plugged. This condition did not seem to have any effect on the engine operation. The air adapter containing the spark plug is shown at the lower left corner of figure 1. Some evidence of the deposits was observed on the spark plug electrodes, but they did not close the gap. The spark plug still operated satisfactorily. The coating on the burner dome was not as thick as it was on the other parts shown in figure 1.

Two of the burner liners are shown in figure 2. These showed a buildup of deposits over small areas just downstream of the air holes in the liners. These deposits were the same type as those that were found in the burner domes and around the fuel nozzles. The rest of the surface of the burner liners had a thin rippled coating of boric oxide. The boric oxide was obviously molten on these surfaces of the liners and was flowing toward the nozzle diaphragm where it built up in clumps at the exit of the burner liners as is shown in figure 3. There was also evidence of molten boric oxide between the outer ring of the nozzle diaphragm and the engine casing shown in figure 3.

A more serious location of the deposit of a rather powdery formation of boric oxide was on the exit screens for the turbine-disk cooling air. This deposit is also shown in figure 3. There was a partial plugging of some of these screens. If these screens become plugged completely, the cooling air that is supplied to cool the rear engine bearing would be blocked off, and this would result in excessive temperatures of this bearing.

The deposit formations on the upstream and the downstream sides of the nozzle diaphragm are shown in figure 4. The deposits on this part are the molten type of deposit. The deposits on the nozzle blades were insignificant. Most of the deposit was found around the outside of the outer diaphragm ring where it would have no effect on the aerodynamic performance of the nozzles. There was also a coating of the deposit on the gas seal rings between the nozzle diaphragm and the turbine rotor.

Photographs of the upstream and the downstream side of the turbine rotor are shown in figure 5. The deposits on this part were very thin.

The boric oxide that formed on the blades evidently was thrown off the blade tips. This flow of the deposits along the blade span is borne out by the nearly radial flow lines that can be seen on the blades in figure 5(a). The pressure surface of the rotor blades was covered with the deposits more completely than the suction surface. Only the tip half of the suction surface (fig. 5(b)) showed evidence of any coating. The turbine rotor disk had no coating of boric oxide on the upstream side but the downstream side showed a very thin, uniform coating.

The tail cone (fig. 6) had a thin coating of boric oxide that had been thrown from the tips of the turbine rotor blades and flowed along the inside surface of the outer exhaust cone. Besides these streams of boric oxide there was a uniform thin coating over the entire inner surface of the tail cone.

There was a thin coating over the inside surface of the tail pipe and a light fringe of the deposit at the exit of the tail pipe nozzle as shown in figure 7. The exhaust-gas thermocouples that were located in the tail pipe had a thick coating on their downstream side, but the coating did not affect the temperature measurements that were made with them.

Effect of Boric Oxide Deposits on Engine Performance

The engine performance with the 50-50 mixture of JP-4 and tributyl borate and with JP-4 fuel alone is summarized in the following table:

	JP-4 only	Operation time with 50-50 JP-4 and tributyl borate fuel mixture, min						
		8	24	34	44	51	60	70
Corrected thrust, lb	3130	3141	3139	3128	3125	3120	3120	3130
Corrected fuel flow, lb/hr	4143	4779	4794	4774	4755	4755	4755	4765
Specific fuel consumption, lb fuel/lb thrust	1.361	1.560	1.568	1.562	1.557	1.560	1.560	1.558
Corrected engine speed, rpm	11,186	11,219	11,208	11,230	11,230	11,230	11,230	11,230
Exhaust-gas temperature, °F	1259	1275	1272	1263	1262	1260	1257	-----

The most significant result shown by this table is the fact that even though desposits were building up in the engine, the engine thrust did not change appreciably during the time when tributyl borate was mixed with the JP-4 fuel. The variation of the engine thrust was from a maximum value of 3141 pounds to a minimum value of 3120 pounds. This variation of 21 pounds is within the reproducibility of the thrust-measuring device. The only change in engine operation when the fuel was changed from JP-4 only to a mixture of JP-4 and tributyl borate was in the specific fuel consumption. The specific fuel consumption with only JP-4 was 1.361 pounds of fuel per pound of thrust. The specific fuel consumption with the fuel mixture was about 1.560 pounds of fuel per pound of thrust. This change in specific fuel consumption is a result of the low heat content of tributyl borate relative to JP-4. The net heating value of the fuel mixture was determined as 16,220 Btu per pound. The net heating value of the JP-4 was 18,675 Btu per pound. The opposite effect would occur if a fuel such as trimethyl diborane, which has a higher heat content than JP-4, were used.

Engine Operation Irregularities

During the operation of the engine with the mixture of JP-4 and tributyl borate, three operating irregularities were noticed. First, after 7 minutes of operation the fuel filter became clogged with a powdery substance and it was necessary to shut down the engine to clean the filter. A second start resulted in the same difficulty. After this second plugging of the filter, the cartridge was left out of the filter case and the tests were completed with no further difficulty. The material collected in the filter was analyzed and was found to be boric oxide, which presumably was formed because of reaction of tributyl borate with traces of moisture in the JP-4 fuel.

The second operating irregularity was noticed when the engine was started with the fuel mixture. The start was rough in that the fuel apparently collected in the engine and suddenly began to burn with a slight explosion.

The third irregularity that was noticed was a white smoke in the exhaust gas leaving the tail pipe. The smoke was probably B_2O_3 that did not deposit in the engine but was carried through the tail pipe as finely divided liquid or solid particles.

SUMMARY OF RESULTS

An experimental investigation was made to determine the quantity and location of boric oxide deposits formed in a turbojet engine when the

engine was operated with a 50-50 mixture of JP-4 fuel and tributyl borate and also to determine whether these deposits affect the engine performance. The results of this investigation are summarized as follows:

1. The greatest accumulation of boric oxide in the engine was found in the burner domes where the air spinners were almost completely plugged and the boric oxide deposits on the fuel nozzles was such as to possibly alter the shape of the fuel spray and decrease the combustion efficiency.

2. The fuel remaining in the nozzles after the engine was shut down hydrolyzed and plugged the fuel nozzles.

3. Deposits at other locations in the engine were thin and showed evidence of being liquid and flowing on the parts in the direction of the gas flow.

4. Filter plugging difficulty was experienced as a result of a boric oxide precipitate forming when some of the tributyl borate combined with traces of moisture in the JP-4 fuel.

5. The deposits that formed in the engine had no effect on the engine thrust or specific fuel consumption during the $1\frac{1}{2}$ hour of engine operation with the tributyl borate and JP-4 fuel mixture.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 22, 1952

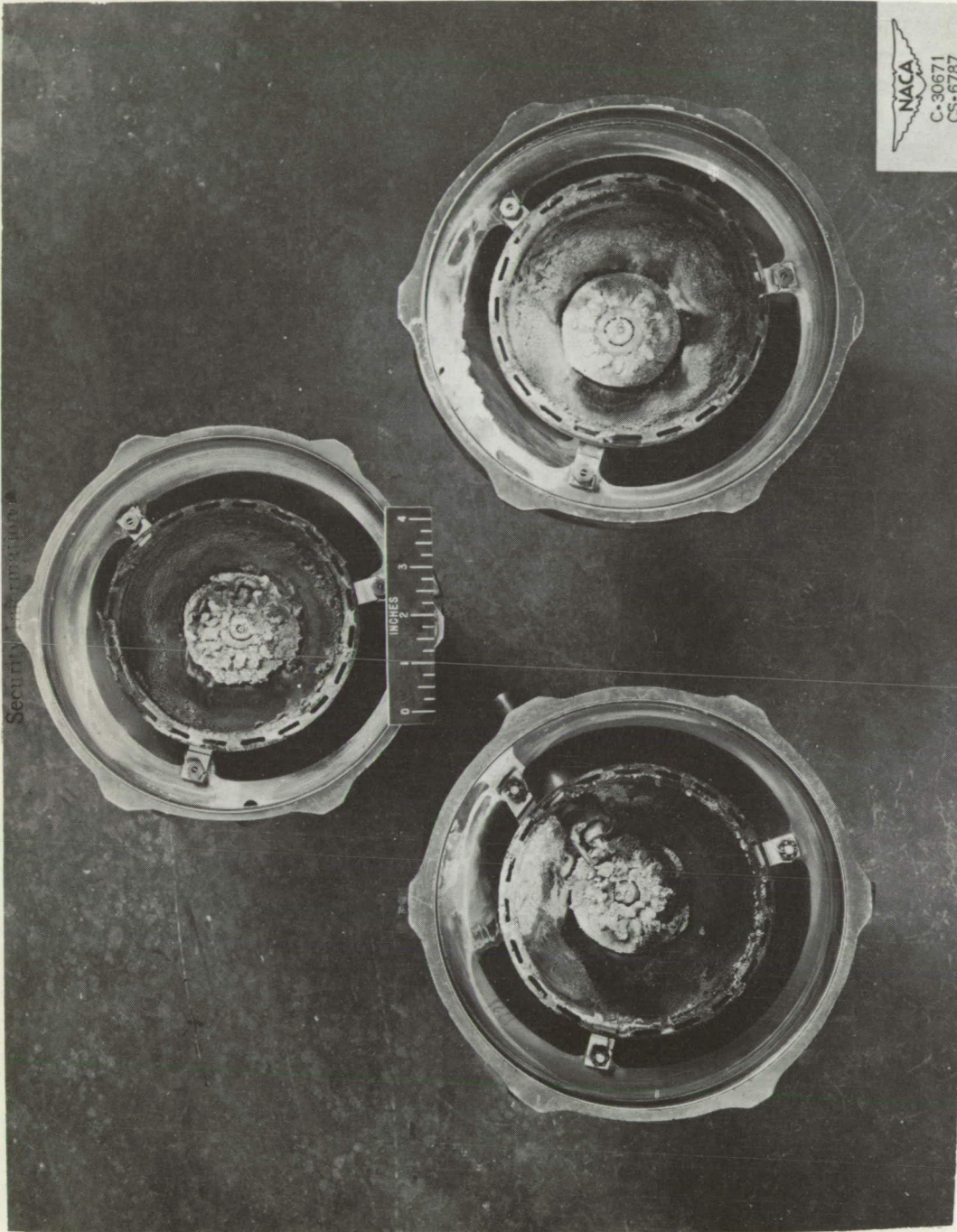


Figure 1. - Build-up of boric oxide deposits on fuel nozzles and burner dome.

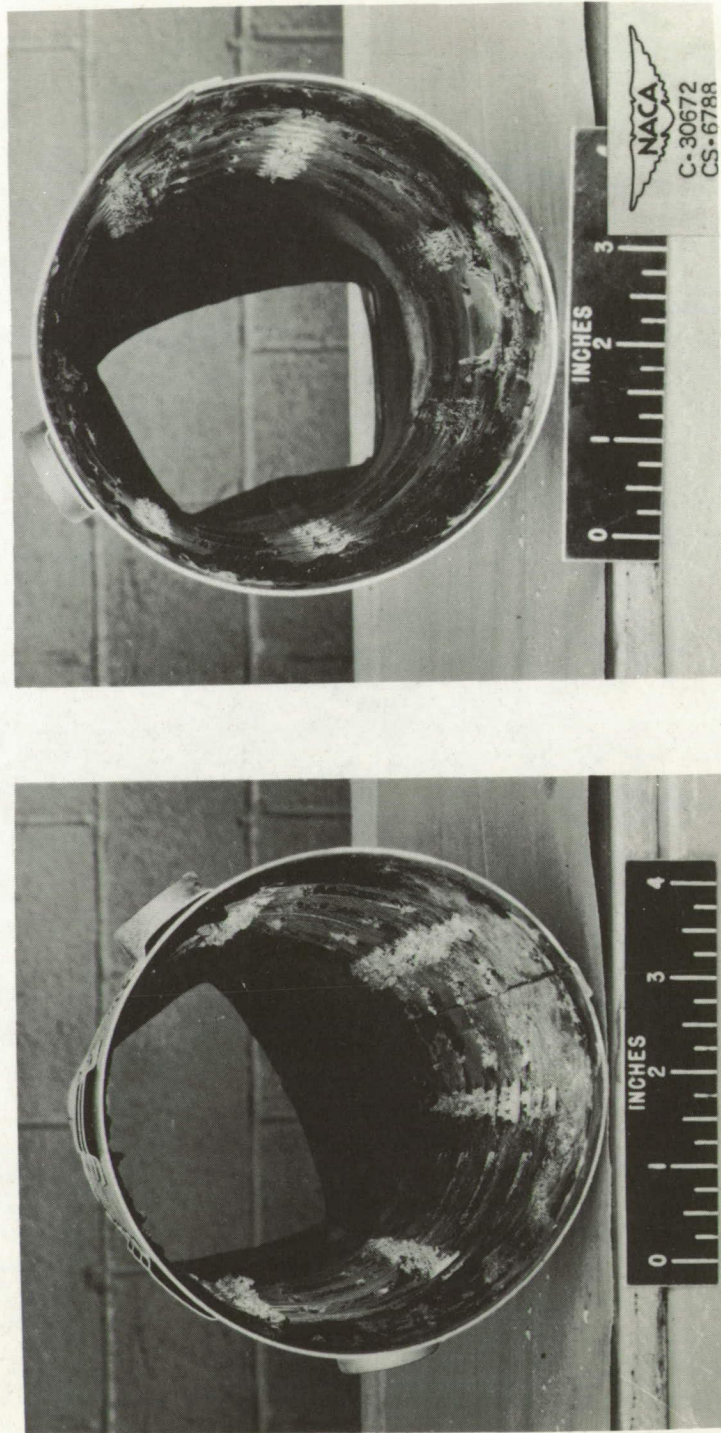


Figure 2. - Build-up of deposits on burner liners.

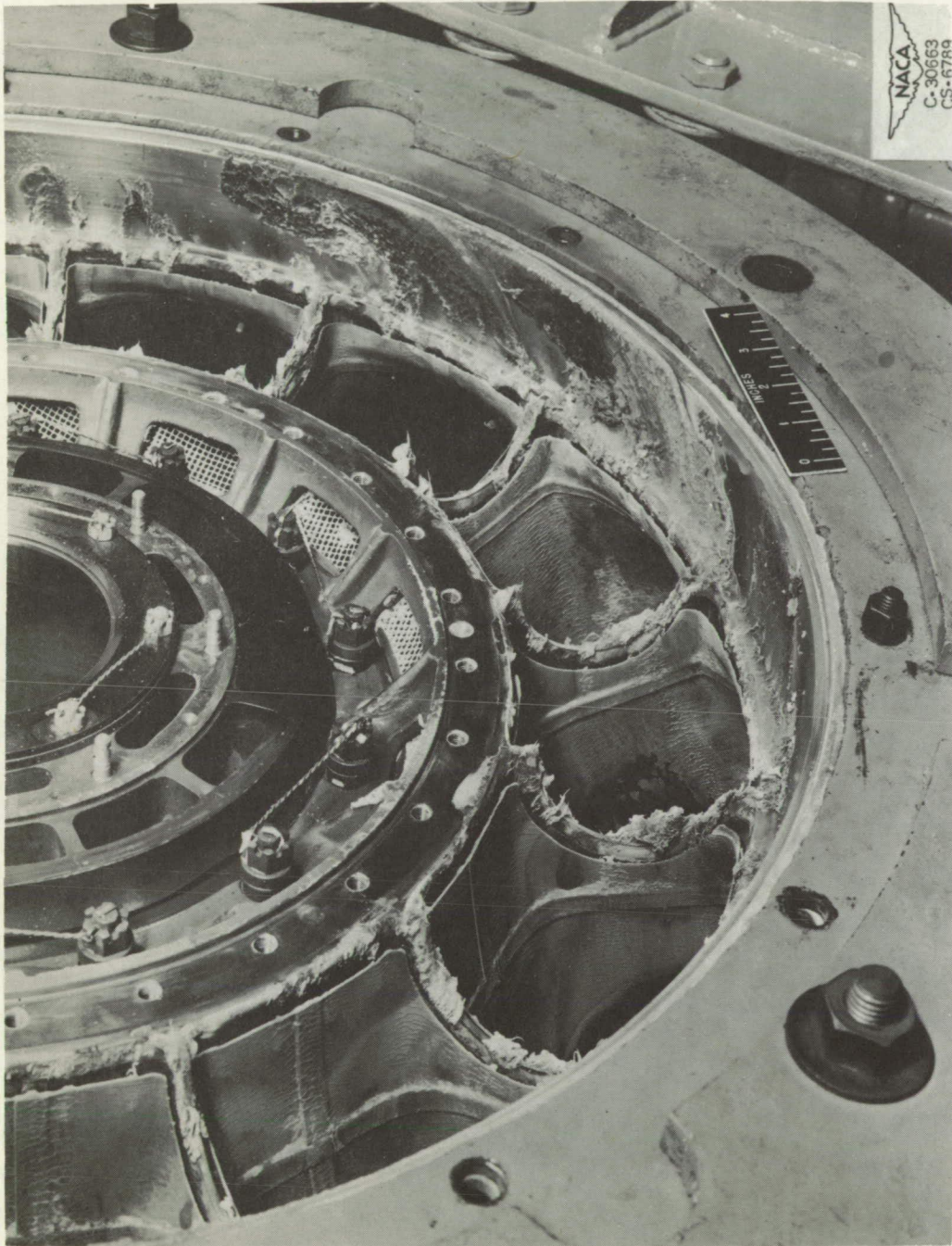
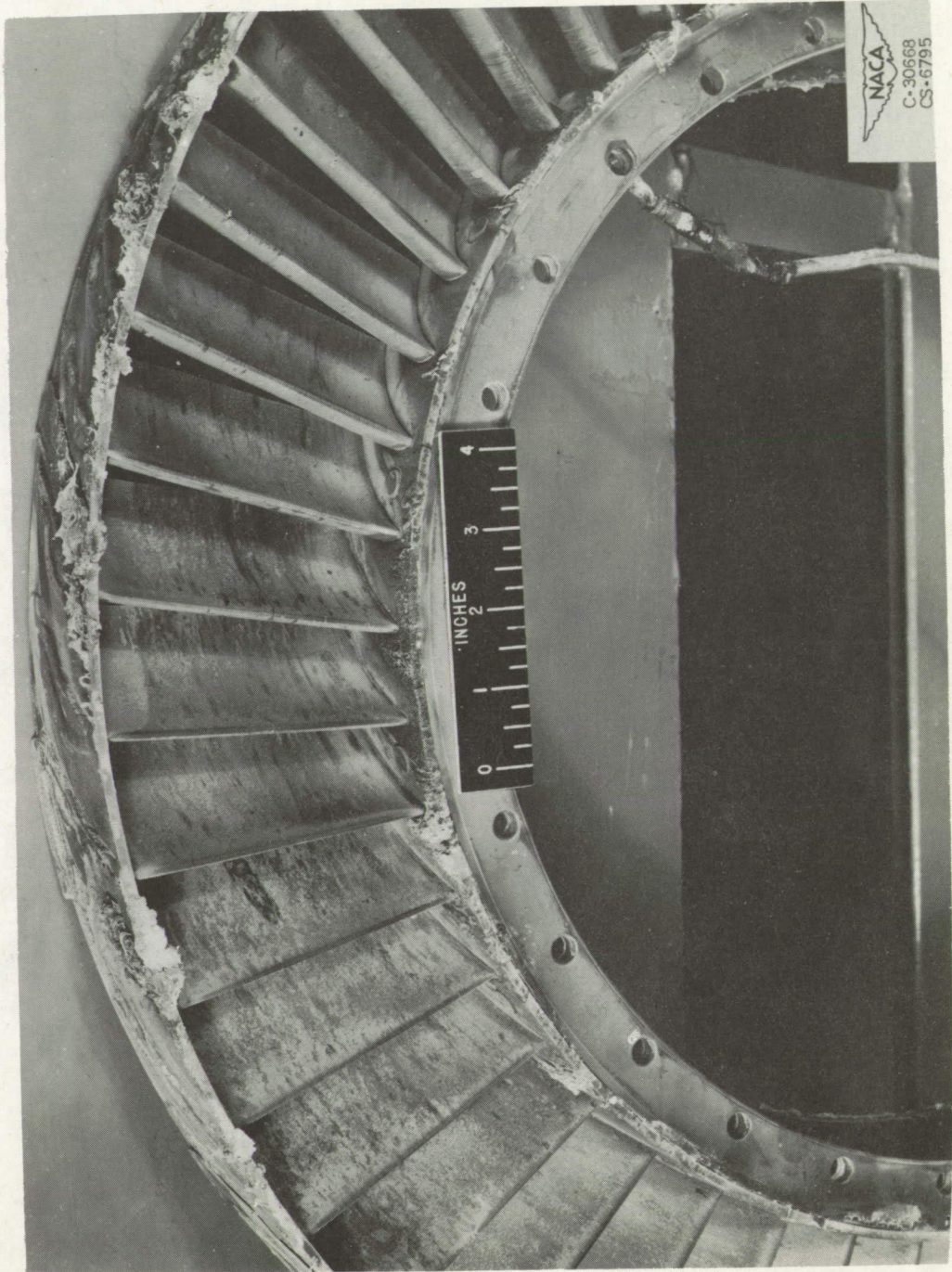
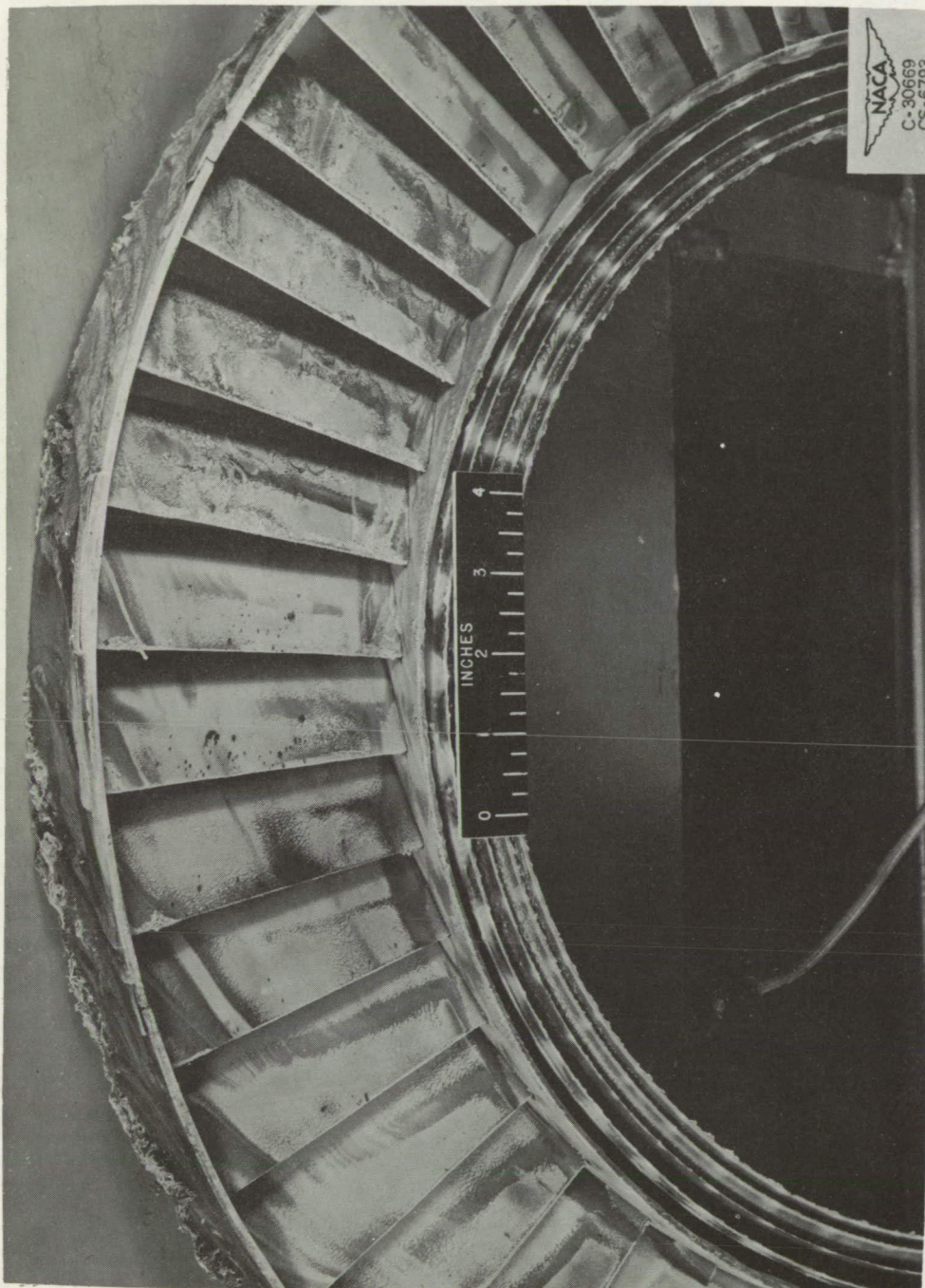


Figure 3. - Build-up of deposits at exit of burners.



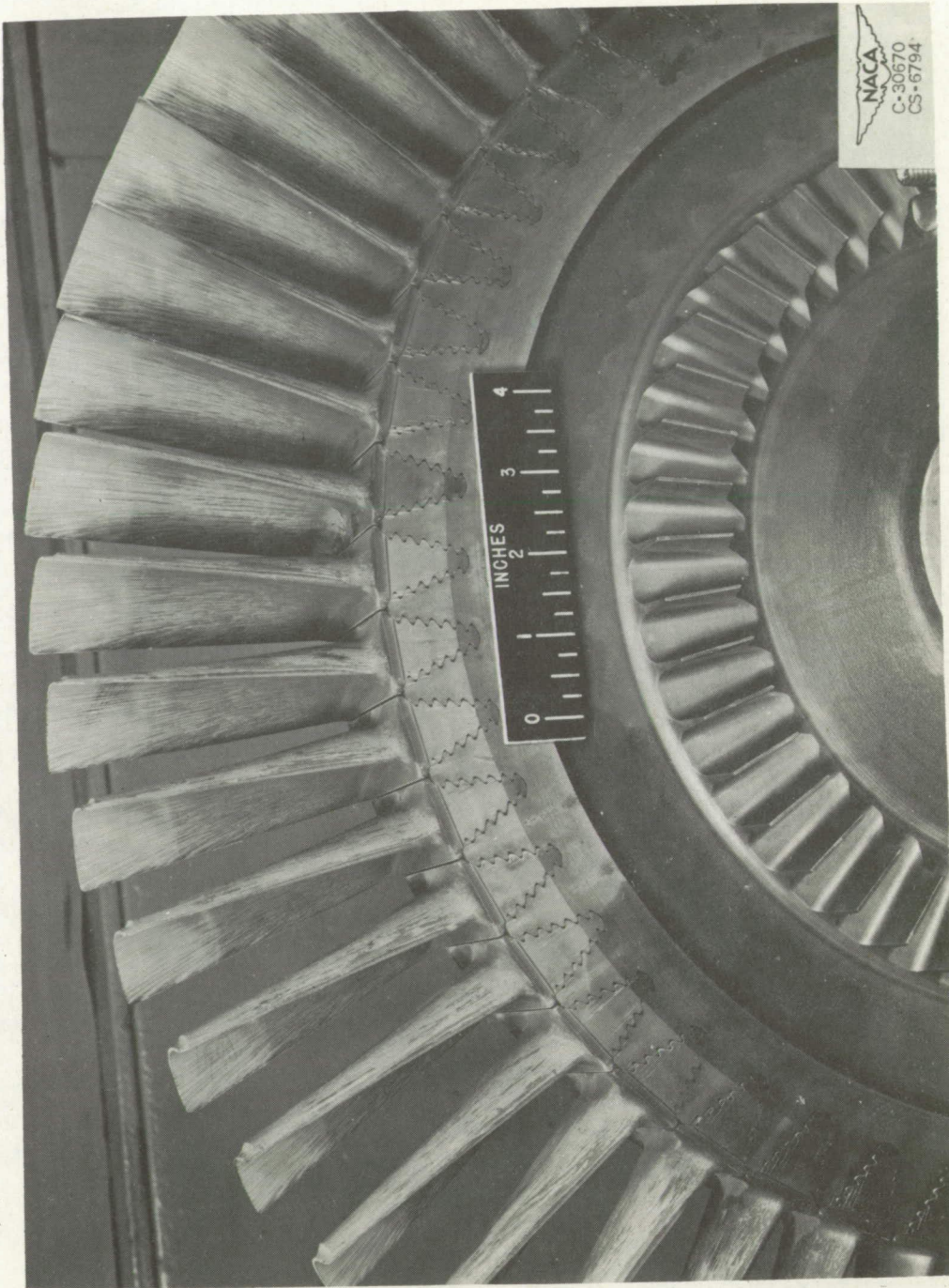
(a) Upstream side of diaphragm.

Figure 4. - Build-up of deposits on nozzle diaphragm.



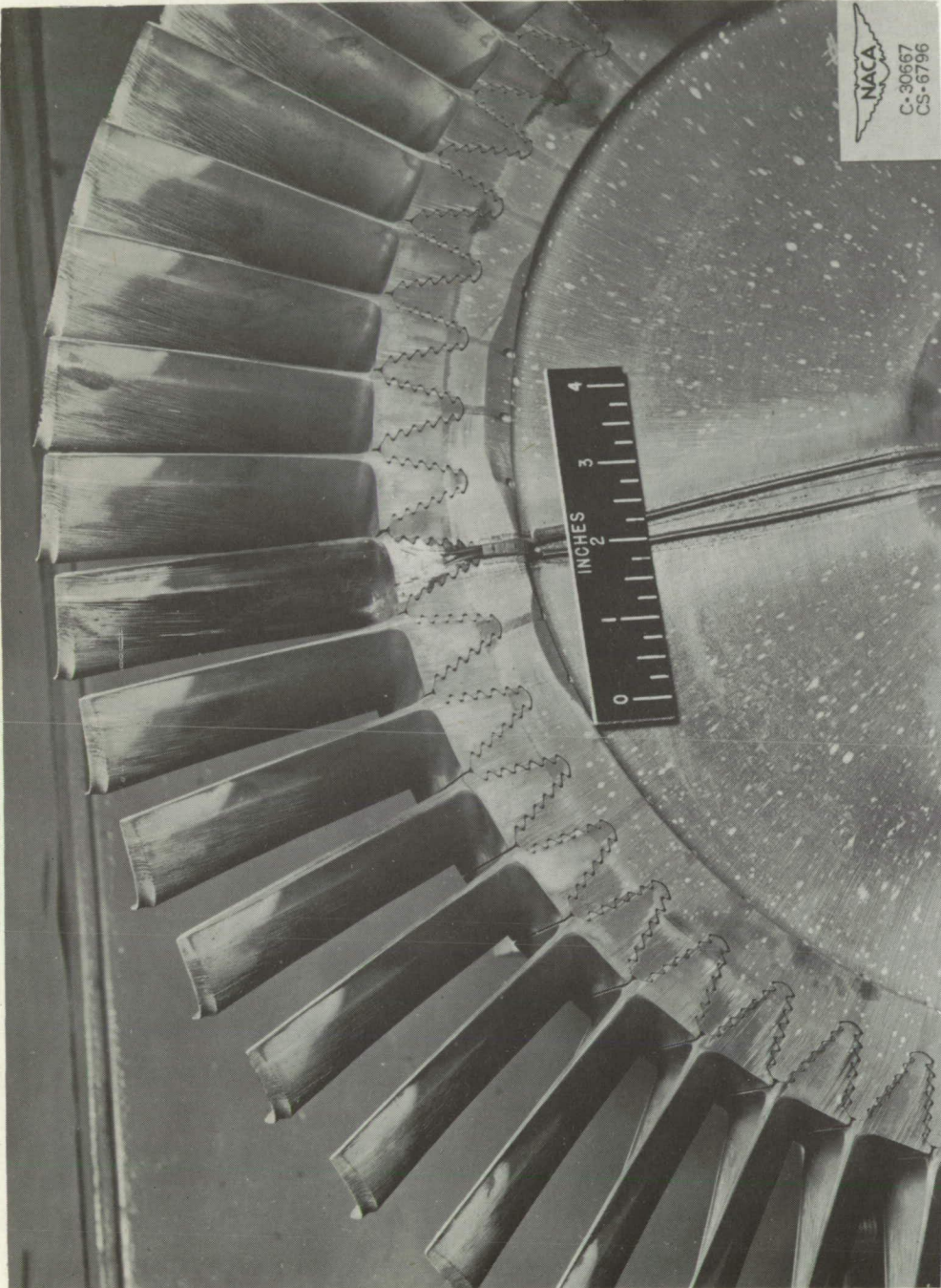
(b) Downstream side of diaphragm.

Figure 4. - Concluded. Build-up of deposits on nozzle diaphragm.



(a) Upstream side of rotor.

Figure 5. - Build-up of deposits on turbine rotor.



(b) Downstream side of rotor.
Figure 5. - Concluded. Build-up of deposits on turbine rotor.

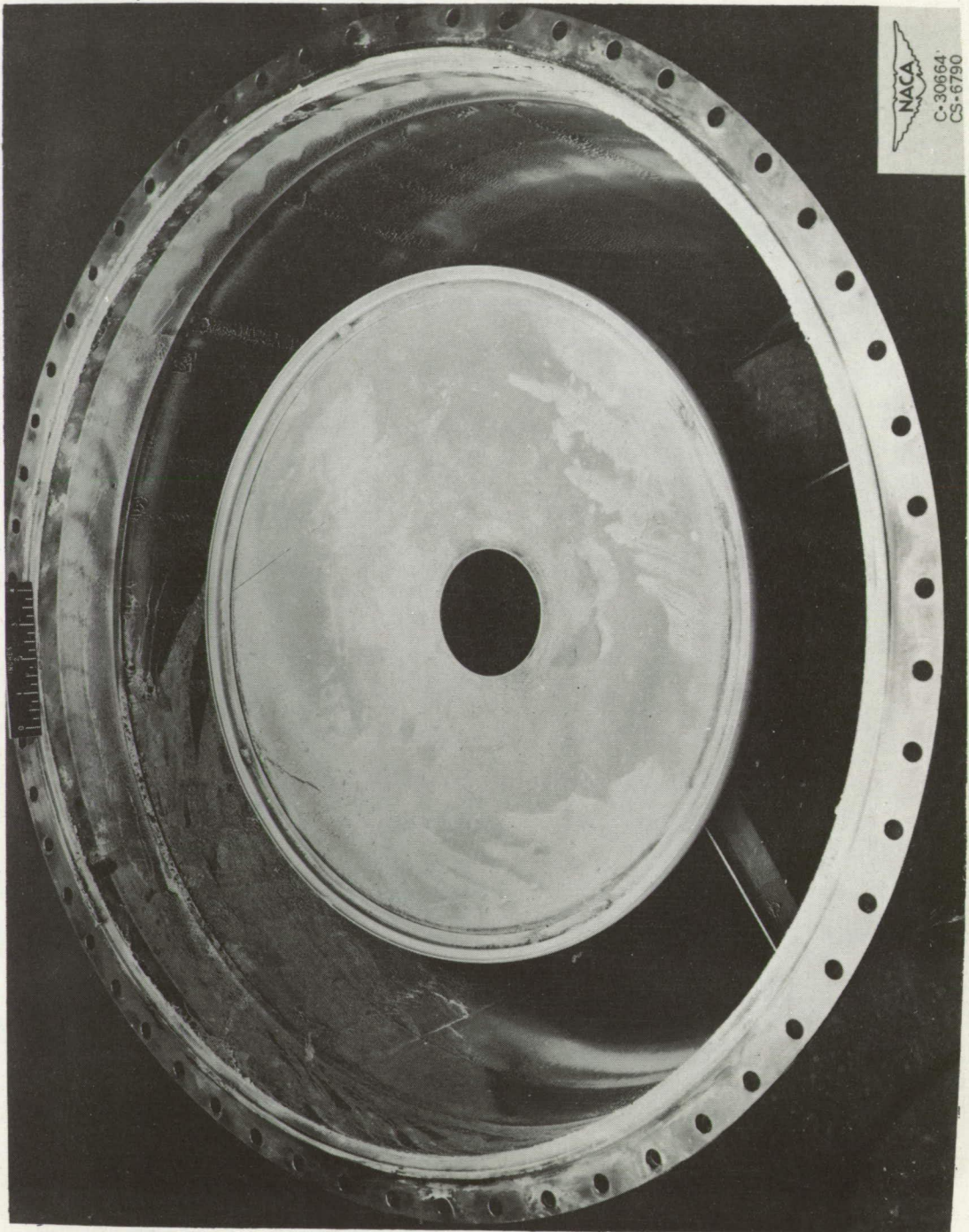


Figure 6. - Build-up of deposits in exhaust tail cone.



Figure 7. - Build-up of deposits on exhaust tail pipe nozzle.