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CORROSION TESTS OF A HEATED WING UTILIZING AN EXHAUST-GAS-AIR MIXTURE FOR ICE PREVENTION

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SUMMARY

An investigation has been made of the extent of corrosive attack in an aluminum alloy wing employing an exhaust-gas-air mixture as a heating medium for ice prevention. The heated mixture was supplied to the wing during 45 hours of flight operations and 100 hours of intermittent ground testing. Sections of the wing interior were painted so a comparison could be obtained between the rates of corrosion in these regions with unpainted sections.

There were no cases of structurally serious corrosion on either painted or plain specimens removed from the wing for detailed microscopic and metallurgical examination. Numerous, small, corrosion splotches were detected in the regions of the wing interior protected with only one coat of zinc-chromate primer, but very few spots of corrosion were located in the sections covered with the primer plus one coat of any one of three selected corrosion-resistant paints.

INTRODUCTION

Extensive flight tests by the NACA (references 1, 2, 3, and 4) have established the practicability of utilizing a portion of the available heat in the engine exhaust gases for the prevention of the accretion of ice on airplane wings, tail surfaces, and windshields. In most of the thermal ice-prevention installations designed and tested by the NACA, the required heat is removed from the exhaust gases through heat exchangers by a quantity of inducted free-stream air, which is then directed to the area to be protected. A visual and metallurgical examination of the wing of the airplane of reference 4, after 225 hours of operation, indicated that the extent of corrosion in a thermal ice-prevention system in which free-stream air is heated and then circulated in the wing interior is negligible. (See reference 5.)

The use of a mixture of exhaust gas and free-stream air as the heating medium in a thermal ice-prevention system has advantages in weight, reliability, and simplicity, when compared to systems utilizing heat exchangers. The major factor which has delayed the acceptance of this type of heating system is the uncertainty regarding the amount of corrosive action which would occur in the interior of the airplane structure.

The present investigation was undertaken to supply information on the extent of corrosion in a representative exhaust-gas-air-mixture wing heating system, and to provide a relative comparison of the corrosion inhibiting qualities of several protective coatings for the wing interior. The scope of the investigation consisted of (1) the thermal design of the wing to establish mixture flow rates which would be representative of those actually required for ice prevention, (2) a check of the thermal performance of the system, (3) the operation of the system for extended periods of time with periodic visual inspections of the wing interior, and (4) a final visual and metallurgical examination of the wing structure.

Appreciation is extended to the National Bureau of Standards for their valuable service in conducting and discussing the metallurgical examinations of the wing specimens as reported herein.

EQUIPMENT AND THERMAL DESIGN OF THE WING

The experimental wing was installed and tested on a light transport airplane with two typical air-cooled radial 450 horsepower engines and is shown in figure 1.

The thermal ice-prevention systems of references 1, 2, 3, and 4, and most subsequent systems, incorporate a double-skin configuration with the inner skin extending to approximately 10 to 15 percent of the chord. The heated air passes through the gap between the two skins and then circulates at ramdom (except in the case of integral fuel tanks) through the wing or empennage interior and discharges to the free stream at the flap or control surface slots. This system would be particularly conducive to corrosion if utilized with an exhaust-gas-air mixture because of the many stagnant areas aft of the double-skin region where the mixture could cool until condensation of corrosive acids occurred. For the wing used in this investigation, therefore, the single-pass spanwise-flow arrangement shown in figure 2 was selected.

The wing leading edge forward of 13.5-percent chord was divided into five spanwise ducts extending from station 132 to 276. The duct boundaries were formed by the outer skin, the continuous spanwise Z-sections supporting the skin, and a thin continuous sheet (pan section in fig. 2) attached to the nose rib flanges. This design appeared to be preferred from a corrosion standpoint, since only the outer skin had to be removed to permit inspection or replacement of all parts exposed to the heating medium. All components of the wing structure were made of aluminum clad 24ST aluminum alloy and were anodized. The exhaust-gas-air mixture was provided by discharging exhaust gas along the center line of an air duct, the forward end of which was exposed to the slipstream dynamic pressure. At station 276 the five spanwise ducts discharged into a common duct along the wing-tip leading edge and thence to free stream.

Design Criteria

The ice-prevention design was based on maintaining the wing skin forward of the 13-percent-chord point at a temperature of 100° F above ambient air during flight in clear air at the normal cruise condition. Although a subsequent investigation (reference 6) has provided a more rational design basis for heated wings, a reanalysis of the system did not appear to be justified, because the empirical basis of a 100° F surface-temperature rise has proved satisfactory for other designs operating under similar flight conditions (references 1, 2, 3, and 4). The airplane cruise conditions selected for the design calculations were 5000 feet pressure altitude, 170 miles per hour true airspeed, and 0° F ambient-air temperature. Two design limitations were: First, the ram air pressure, plus whatever was gained from the ejector-mixer, was to be adequate to circulate the mixture through the wing duct system; and, second, the temperature of the mixture should not be greater than 300° F because higher temperatures might decrease the corrosion resistance of the clad 24ST aluminum alloy. (See reference 5.)

Design Procedure

The design procedure consisted of calculating the cross-sectional areas of the five ducts and the mixture flow rate in each duct to provide the required surface-temperature rise without exceeding the allowable pressure drop. Since design procedures are well established (references 6, 7, 8, and 9) the detailed calculations for this system are not presented. Calculations indicated that the desired mixture temperature of 300° F would be obtained by utilizing the exhaust gas from only two cylinders. This would result in an exhaust-gas-air ratio of about 1 to 5 by weight. Resulting calculated surface-temperature rises, mixture flow rates, mixture temperatures and cross-sectional areas for the five ducts at spanwise stations 132, 204, and 276 are listed in table I.

INSTRUMENTATION

Flight conditions of altitude, airspeed, and ambient-air temperature were recorded with standard NACA research instruments. Temperature and pressure instrumentation was provided to measure wing-surface temperatures and mixture temperatures, dew points and flow rates. The wing instrumentation was the same for both flight and ground tests.

The instrumentation for the temperature measurements was identical for each spanwise duct and was repeated at wing stations 136, 200, and 272. The installation of the instrumentation at the exact wing stations used in the design was not practical. Surface temperatures were obtained through the use of iron-constantan thermocouples, 0.002 inch thick, cemented to the outer surface of the leading-edge skin. Unshielded iron-constantan thermocouples, supported by small copper tubing, were centered in each duct at each wing station to measure the temperature of the mixture.

All temperatures were indicated by a self-balancing indicating potentiometer connected to the thermocouples through a selector switch and were recorded manually. The potentiometer was checked before and after the taking of each set of temperature data with a calibrated thermocouple maintained at 32° F. An estimated over-all error in the temperature measurements of ±5° F was based primarily upon installation error.

To measure the dew-point temperature of the exhaust-gas-air mixture, a portion of the mixture from the main supply duct was ducted to the airplane cabin and passed through a sealed box containing wet- and dry-bulb thermometers. The presence of small quantities of vapor other than water could cause some error in the indication of the wet-bulb thermometer, but this error was considered to be negligible due to the preponderance of the water vapor.

Pressure instrumentation in the wing consisted of total-pressure probes located in the center of each duct at wing stations 134 and 270, and static pressure orifices in each duct at station 270. The pressures were recorded by photographing a manometer board.

Mixture flow rates were measured by means of static orifices and total-pressure probes at station 270 which were calibrated with a 2-inch orifice meter. During calibration, air was supplied from a blower to only one duct at a time. Means for varying the flow rate in each duct was provided by a small adjustable tab in each duct at wing station 276.

TESTS AND RESULTS

Preliminary Tests

Due to the large number of organic finishes available as protective coatings, some initial tests were made to eliminate the less suitable ones. These tests consisted of repeatedly heating painted samples of 24ST aluminum alloy to various temperatures up to 300° F and then immersing them in exhaust-gas condensate. Three finishes were selected which showed no deterioration during the tests other than slight dulling or discoloration. The selected finishes A, B, and C are defined as follows:

A. Oil modified phthalic alkyd varnish, clear

B. Heat-resistant varnish, light amber color, composition not furnished by manufacturer

C. Heat-resistant enamel, glyceryl phthalate, black, AN-TT-E-501

Figure 3 shows the location of the sections painted on the inner surface of the leading-edge skin. The painted skin and pan section forming the wing ducts are shown prior to installation on the wing in figures 4 and 5.

The duct surfaces were prepared and painted in the following steps: (1) the base metal of 24ST clad aluminum alloy was anodized after subassembly of parts was completed, (2) all surfaces were cleaned with alcoholic phosphoric acid in accordance with Army Air Forces T. O. No. 01-1-1, (3) one thin coat of zinc-chromate primer AN-TT-P-656b was sprayed over all of the cleaned surfaces, and (4) a single coat of one of the three protective finishes was brushed onto different spanwise sections.

Initial ground tests of the thermal system consisted of performance tests of the ejector mixing unit, calibration of the wing pressure orifices, and adjustment of the flow rates in each spanwise duct.

Flight Tests

The first series of flight tests was made in clear air at design conditions to check the calculated surface temperatures and mixture flow rates. The results of a typical flight are presented in table II. Measured surface-temperature rises above ambient-air temperature were not in good agreement with the analysis. This was attributed partly to the difference between theoretical and actual mixture temperatures at the entry to the wing ducts and somewhat to the difference between theoretical and actual flow rates. In spite of the poor agreement obtained, the range of temperatures and flow rates measured were considered satisfactory for the service tests to determine the corrosive effect of the mixture.

Since the degree of corrosion to be anticipated would be directly proportional to the amount of mixture condensation, the relation of the mixture dew point to the temperature of the adjacent surfaces was considered to be an important factor in the investigation. The dew points calculated from the indications of the wet- and dry-bulb thermometers varied from 76° to 106° F over the altitude range of 1,000 to 10,000 feet. These values are in agreement with a computed value (see appendix for method of computation) of 90° F based on engine operation data, and mixture flow rates and temperatures obtained during flight at design conditions. These calculated and observed dew-point temperatures are above the lower range of surface temperatures of 60° to 80° F, (references 1, 2, 3, 4, and 10), usually associated with heated wings during icing conditions. During the flight tests, however, surface temperatures below the mixture dew point could not be obtained with the available cloud conditions, hence the decision was made to complete the corrosion tests on the ground.

A total of 45 hours and 12 minutes of flight time with the mixture supplied to the wing was accumulated before the termination of the flight tests. Inspection of the leading-edge skin and pan section revealed a sooty deposit in the duct regions, but no visual indication of corrosion.

Ground Tests

The right wing complete with instrumentation was removed from the airplane and installed near an engine test stand as shown in figure 6. Exhaust gas was supplied by an aircraft engine identical to those on the test airplane, and air was supplied by a blower providing ram-air pressures equivalent to the flight values. A water spray maintained the leading-edge-surface temperatures near 65° F. Data from a typical ground test are presented in table III. The dew-point temperature of the mixture for this test was calculated to be 75° F, and this value was verified through measurements with dry- and wet-bulb thermometers. For most of the ground tests the measured dew-point temperatures ranged from 68° to 77° F.

Duration of each test conducted with the wing heated by the exhaust-gas-air mixture was 1 to 3 hours on every other day to simulate the intermittent use that would be experienced under normal flight operations and icing encounters. After a test the wing was not purged, and the residual exhaust gases and condensate were allowed to remain within the ducts. Since a major inspection of operational aircraft is usually required at least every 1000 hours of flight time, and since icing is normally encountered less than 10 percent of the total flight time, 100 hours of ground testing were considered to satisfactorily represent the maximum period between inspections. The ground tests covered a total time of 9 months.

Inspections of the inside of the wing ducts were made after 25, 50, 75, and 100 hours of heated-wing operation at the engine test stand. No corrosion of any significance was observed during the 25-, 50-, and 75-hour inspections. After the completion of the tests (100 hours), a few spots indicating possible corrosive attack were detected on the outer skin. An exceptional concentration of these spots is shown in figure 7. No spots were detected on the pan section, which is consistent with the fact that the pan-section temperatures were above the dew-point temperature of the mixture.

Micro-examinations

Representative specimens of the wing metal exposed to the mixture were selected primarily from locations in the leading-edge skin of the right wing, as shown in figure 3 and defined in table IV. The samples were chosen to include any region where a small splotch of corrosion was detected with a surface microscope. To be sure that there was no hidden corrosion in the pan section, one sample of the pan skin and a cross section of one of the Z-sections were selected. The samples were cut out of the leading-edge skin and pan sections and sent to the National Bureau of Standards in the sizes shown in figure 8. Regions marked on the specimens with white lines are the locations of the sections removed by the Bureau for detailed microscopic and metallurgical examination. Specimens 13 through 17 were taken from three aluminum strips (partly painted in the same manner as the test wing and partly bare, as shown in table IV) which were attached to the leading-edge skin during ground test-stand operations. Specimen 13 was plain 24ST aluminum alloy and was not aluminum clad or painted, hence should give an indication of the corrosion to be expected in a completely unprotected aluminum alloy wing.

DISCUSSION

Microscopic examinations disclosed that the aluminum clad layer over the 24ST aluminum alloy of the wing structure had not been completely penetrated in any case by corrosive attack. The degree of penetration at a visible 1/16-inch-diameter splotch on specimen 4 removed from the leading-edge skin of duct 3 at station 162 is shown in figure 9(a). About half the thickness of the clad layer was removed by corrosive attack which was more severe than that on any other specimen except 11, 13, 16, and 18.

Diffusion of the core material into the clad layer (caused by overheating) occurred in all specimens from 7 to 20, inclusive, except 13 which was not clad. A typical example of this diffusion is shown in figure 9(b), and according to the National Bureau of Standards, ". . . could have resulted from either or both of two causes; (1) overheating of the material prior to its assembly in the wing skin, or (2) overheating of the wing by the hot exhaust gases." The locations of specimens 7 to 20 were all in one of the two sheets of material used to fabricate the leading-edge skin and were part of the outboard section. Inasmuch as the outboard portion of the wing during flight tests was never at higher temperatures than the inboard section, and the ground tests were conducted at low temperatures, it is apparent that overheating of the outboard section occurred during manufacture or fabrication.

Specimen 11 was taken from the previously mentioned overheated section of the skin where the corrosion splotches were the most evident and concentrated. The corrosive attack was more severe than on specimen 4 and had penetrated to the diffusion zone, yet had not reached the core material. Both specimens were protected by only the one coat of zinc-chromate primer.

A magnified cross section of specimen 11 is shown in figure 9(c), which is also typical of spots of corrosive attack in specimens 16 and 18. The corrosion splotch in specimen 18 was unexpected, since the initial visual inspection indicated that the organic finish was completely intact with its original gloss. Although care was exercised during fabrication to use only unblemished material, this one spot of corrosion could have been in the sheet of metal prior to the application of the protective finish. The efficacy of extra coats of zinc-chromate paint or of the corrosion-resistant organic finishes was indicated by visual macro-examinations and verified by the micro-examinations of specimens 19 and 20. The clad layer on these specimens had been completely gouged out in the region of rivet gun scars, yet there was no evidence of corrosion of the core material at the bottom of the scars.

Figure 9(d) illustrates the intergranular corrosion which would have occurred if bare 24ST aluminum alloy had been used in the wing ducts or if the rivet scars of specimens 19 and 20 had not been painted over with zinc-chromate paint or other protective finishes. This corrosion was located at the bottom of a pit in specimen 13 (a strip of bare 24ST aluminum alloy attached to the inner surface of the leading-edge skin during the 100 hours of ground testing).

There were no cases of corrosive attack on any of the specimens removed from either the test wing or strips attached to the wing which the National Bureau of Standards would classify as structurally serious with marked decrease in the strength of the material.

The applicability of the results presented in this report to the prediction of corrosion tendencies of a heated wing utilizing a mixture of air and the exhaust gases from a turbine-type airplane engine would depend upon the similarity between the products of combustion of turbine-engine and reciprocating-engine fuels, and the percent of dilution of the exhaust gases of each with air. The corrosive acids formed in the condensate from the products of combustion of petroleum hydrocarbons are primarily compounds of sulphur and bromine derived from impurities in the fuel. The specifications listed by the military services for jet fuel JP-1, AN-F-32a (kerosene) limit the impurities to values closely comparable with reciprocating engine gasoline, AN-F-48a, except for the sulphur content. The sulphur content in gasoline must not exceed 0.05 percent by weight compared with a maximum allowable 0.20 percent by weight in kerosene. This would indicate a corrosive potential for the kerosene, per pound of fuel, four times greater than for gasoline, but since jet engines operate at fuel-air ratios of approximately one-third to one-tenth the values for reciprocating engines, the corrosive potential, per pound of exhaust gas, should be of the same order of magnitude for aviation gasoline and kerosene.

CONCLUSIONS

As a result of flight and ground tests of an exhaust-gas-air-mixture wing thermal ice-prevention system certain conclusions can be stated. These conclusions are only directly applicable to systems geometrically similar to that tested and for the same conditions of operation; however, they may be extended with discretion to provide an indication of the corrosive possibilities for conditions other than those tested.

1. The extent of corrosive action in the single-pass spanwise-flow system was not structurally serious after 100 hours of exposure to the exhaust-gas-air mixture, even for unprotected 24ST aluminum alloy.

2. Indications of corrosive action after 100 hours of operation of such a system in the cases where 24ST aluminum alloy, clad 24ST aluminum alloy, or clad 24ST aluminum alloy plus one coat of zinc-chromate primer comprise the leading-edge structure, may require the replacement of portions of the leading-edge structure at that time.

3. Coating of the leading-edge interior with any of the three protective organic paints over a coat of zinc-chromate primer will extend the service life of the structure beyond 100 hours of exposure to an exhaust-gas-air mixture.

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APPENDIX

CALCULATION OF DEW-POINT TEMPERATURE OF MIXTURE

The conditions selected for this sample calculation were from a typical test flight which duplicated the design flight conditions. Exhaust gas from two cylinders of the engine, burning 100/130 octane aeronautical fuel AN-F-28, was used in the mixing unit to provide the exhaust-gas-air mixture for the spanwise-flow wing.

Engine data.–

Revolutions per minute	1800 rpm
Manifold pressure	22 in. Hg
Brake horsepower	300 hp
Engine displacement	985 cu in.
Fuel consumption	0.47 lb/bhp–hr

Flight data.–

Pressure altitude	5000 ft
Indicated airspeed	150 mph
Ambient–air temperature	63° F

Fuel–flow rate, two cylinders.–

$$300 \times 0.47 \times 2/9 = 31.35 \text{ lb fuel/hr}$$

Air–flow rate to engine.– The complete engine displacement of 985 cubic inches or 0.57 cubic foot occurs for every two revolutions of the engine. Estimating the volumetric efficiency of the engine to be 85 percent, the weight rate of air flow to the engine equals:

$$\frac{0.57 \text{ cu ft}}{2 \text{ rev.}} \times 1800 \frac{\text{rev.}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times 0.0765 \frac{\text{lb}}{\text{cu ft}}$$

$$\times \frac{22 \text{ in. Hg}}{29.92 \text{ in. Hg}} \times 0.85 = 1471 \text{ lb air/hr}$$

Air–flow rate, two cylinders.–

$$1471 \times 2/9 = 327 \text{ lb air/hr}$$

Exhaust–gas flow rate, two cylinders.–

Air–flow rate plus

fuel weight rate: $327 + 31 = 358$ lb exhaust gas/hr

Equation for complete combustion of octane fuel (reference 11).- (Octane is an average hydrocarbon in gasoline.)

$$C_8H_{18} + 12.5\ O_2 + 47.2N_2 = 9H_2O + 8\ CO_2 + 47.2\ N_2$$

Relative weights:

$$114 + 400 + 1322 = 162 + 352 + 1322$$

Weight/lb of fuel:

$$1 + 3.51 + 11.6 = 1.42 + 3.09 + 11.6$$

Note: Resulting water = 1.42 lb H_2O/lb fuel

Exhaust-gas-air-mixture flow rate.-

1662 lb/hr from test data.

Water in mixture from combustion.-

$$1.42\ \frac{\text{lb } H_2O}{\text{lb fuel}} \times 31.35\ \frac{\text{lb fuel}}{\text{hr}}$$

$$\times \frac{1}{1662}\ \frac{\text{hr}}{\text{lb mixture}} = 0.02675 \text{ lb water/lb mixture}$$

Percentage of mixture weight derived from fresh air supply.-

$$\frac{1662 - 358}{1662} \times 100 = 78.47 \text{ percent}$$

Water in mixture from fresh air supply.- (Data from steam tables of reference 12.)

Specific volume of vapor at 63° F, v = 1091.4 cu ft/lb

Assuming a relative humidity of 70 percent, the specific weight of the vapor $\gamma_v = 0.70 \times \frac{1}{1091.4} = 0.000641$ lb/cu ft

Pressure of the mixture at 5000 feet, $p_m = 12.21$ lb/sq in.

Partial pressure of the vapor at 63° F, $p_v = 0.285$ lb/sq in.

Partial pressure of the air, $p_a = p_n - p_v = 11.925$ lb/sq in.

Specific weight of the air,

$$\gamma_a = \frac{p_a}{R\ T_a} = \frac{11.925 \times 144}{53.3 \times 523} = 0.0616 \text{ lb/cu ft}$$

$$\text{Specific humidity} = \frac{\gamma_v}{\gamma_a} = \frac{0.000641}{0.0616} = 0.01041 \ \frac{\text{lb water}}{\text{lb dry air}}$$

Therefore the water in the mixture from the fresh air supply is equal to $0.01041 \times 0.7847 = 0.00817$ lb water/lb mixture.

Total water in mixture.- Summation of the water contained in the exhaust gas and the water from the fresh air supply is equal to $0.02675 + 0.00817 = 0.03492$ lb water/lb mixture.

Composition of the exhaust gas-air mixture by volume.- One lb of mixture contained 0.0349 lb water vapor and 0.9651 lb dry gases.

Fuel burned per pound of mixture $= \frac{31.35}{1662} = 0.01886$ lb fuel/lb mixture.

Composition of gases by weight was determined from the combustion equation assuming complete combustion:

$$C_8H_{18} + 12.5\ O_2 + 47.2\ N_2 = 9H_2O + 8CO_2 + 47.2\ N_2$$

Weight/lb of fuel:

$$1 + 3.51 + 11.6 = 1.42 + 3.09 + 11.6$$

Weight/lb of mixture:

$$0.01886 + 0.0662 + 0.02189 = 0.0268 + 0.0583 + 0.2189$$

The weight of oxygen and nitrogen per pound of mixture from the fresh air supply is 0.9651 – 0.0583 – 0.2189 = 0.6879 lb. Inasmuch as the composition of air by weight is approximately 23.1 percent O_2 and 76.9 percent N_2, there was $0.6879 \times 0.231 = 0.1589$ lb O_2 and $0.6879 \times 0.769 = 0.529$ lb N_2. Total nitrogen = 0.2189 + 0.529 = 0.7479 lb N_2. The composition of the mixture by weight was converted to percentages by volume in the following manner (reference 11):

1 Gas	2 Weight (lb)	3 Percent by weight	4 Molecular weight	5 3/4	6 Percent by volume 5/3.492×100
N_2	0.7479	74.79	28	2.67	76.45
O_2	.1589	15.89	32	.4963	14.21
CO_2	.0583	5.83	44	.1323	3.79
H_2O	.0349	3.49	18.016	.1937	5.55
	1.0000	100.00		3.4923	100.00

<u>Dew-point temperature of the mixture.</u>– The partial pressure of the water vapor is the pressure of the mixture times the percentage of water vapor present in the mixture. The total pressure of the mixture in the wing varied from 12.2 to 12.7 lb per sq in., so the saturation or dew-point temperatures corresponding to the partial pressure of the water vapor varied as shown in the following table:

Mixture pressure (lb/sq in.)	Water percent by volume	Partial pressure water vapor (lb/sq in.)	Dew-point temperature[1] (°F)
12.2	5.55	0.677	89
12.7	5.55	.705	90.3

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TABLE I.– RESULTS OF THE DESIGN CALCULATIONS
FOR THE EXHAUST-GAS-AIR MIXTURE HEATED WING

Duct designation[1]	Wing station[1]	Cross-sectional area (sq in.)	Surface temperature rise (°F)	Mixture temperature (°F)	Mixture flow rate[2] (lb/hr)
1	132	2.62	121	300	200
1	204	1.85	104	215	200
1	276	.94	98	166	200
2	132	4.88	104	300	235
2	204	2.94	104	238	235
2	276	1.4	113	196	235
3	132	6.11	93	300	765
3	204	4.67	93	268	765
3	276	3.5	78	204	765
4	132	3.73	105	300	240
4	204	2.33	100	231	240
4	276	1.2	132	191	240
5	132	2.5	140	300	90
5	204	1.75	107	208	90
5	276	.96	99	155	90

[1] See figure 2.

[2] Resultant total mixture flow rate, 1530 pounds per hour.

Selected conditions for design calculation:

Free-air temperature	0° F
Altitude	5000 ft
True airspeed	170 mph

TABLE II.- SURFACE-TEMPERATURE RISES, MIXTURE TEMPERATURES, AND FLOW RATES MEASURED DURING FLIGHT TESTS OF THE EXHAUST-GAS-AIR MIXTURE WING AT DESIGN CONDITIONS

Duct designation	Wing station	Surface temperature rise (°F)	Mixture temperature (°F)	Mixture flow rate[1] (lb/hr)
1	136	95	346	188
1	200	55	233	188
1	272	50	180	188
2	136	105	399	225
2	200	78	292	225
2	272	85	225	225
3	136	160	403	880
3	200	119	347	880
3	272	112	296	880
4	136	152	347	269
4	200	100	- -	269
4	272	102	223	269
5	136	105	275	100
5	200	60	191	100
5	276	54	157	100

[1] Total mixture flow rate, 1662 pounds per hour.

Flight conditions:

Free-air temperature	63° F
Altitude	5000 ft
True airspeed	166 mph

TABLE III.- SURFACE TEMPERATURES OF THE EXHAUST-GAS-AIR-MIXTURE HEATED WING DURING A TYPICAL GROUND TEST

Duct designation	Wing Station	Surface temperature[1] (°F)
1	136	75
1	200	63
1	272	52
2	136	63
2	200	61
2	272	63
3	136	63
3	200	60
3	272	83
4	136	67
4	200	58
4	272	77
5	136	73
5	200	59
5	272	63

[1] Surface temperatures are average readings from several thermocouples.

Total mixture flow rate, 1490 lb/hr

Calculated dew-point temperature of mixture, 75° F

TABLE IV.- SPECIMENS SELECTED FOR METALLURGICAL EXAMINATION FROM EXHAUST-GAS-AIR-MIXTURE WING

Specimen[1]	Wing station	Duct	Material	Paint[2]	Total heat time
1	140	3	0.064 Anodized Clad 24ST Aluminum Alloy	Zinc-Chromate and Paint A	Flight time, 45 hr 12 min Test stand, 100 hr
2	147	3	Do.	Zinc-Chromate	Do.
3	155	3	Do.	Zinc-Chromate and Paint B	Do.
4	162	3	Do.	Zinc-Chromate	Do.
5	169	3	Do.	Zinc-Chromate and Paint C	Do.
6	184	2	0.032 Anodized Clad 24ST Aluminum Alloy	Zinc-Chromate	Do.
7	200	1	0.064 Anodized Clad 24ST Aluminum Alloy	Do.	Do.
8	200	2	Do.	Do.	Do.
9	200	3	Do.	Do.	Do.
10	200	4	Do.	Do.	Do.
11	200	5	Do.	Do.	Do.

[1] See figure 3.

[2] See page 5.

TABLE IV.- CONCLUDED.

Specimen[1]	Wing station	Duct	Material	Paint[2]	Total heat time
12	204	2 and 3	0.064 Anodized Clad 24ST Aluminum Alloy	Zinc-Chromate and Paint A	Flight time, 45 hr 12 min Test stand, 100 hr
13[3]	242	3	0.020 24ST Aluminum Alloy	Not painted	Test stand, 100 hr
14[3]	243	3	Do.	Do.	Do.
15[3]	244	3	Do.	Zinc-Chromate	Do.
16[3]	245	3	0.020 Anodized Clad 24ST Aluminum Alloy	Not painted	Do.
17[3]	248	3	Do.	Zinc-Chromate and Paint A	Do.
18	259	3	0.064 Anodized Clad 24ST Aluminum Alloy	Zinc-Chromate and Paint B	Flight time, 45 hr 12 min Test stand, 100 hr
19	263	3	Do.	Zinc-Chromate	Do.
20	266	3	Do.	Zinc-Chromate and Paint C	Do.

[1] See figure 3.

[2] See page 5.

[3] These are specimens from three metal strips attached to leading-edge skin during ground test operations.

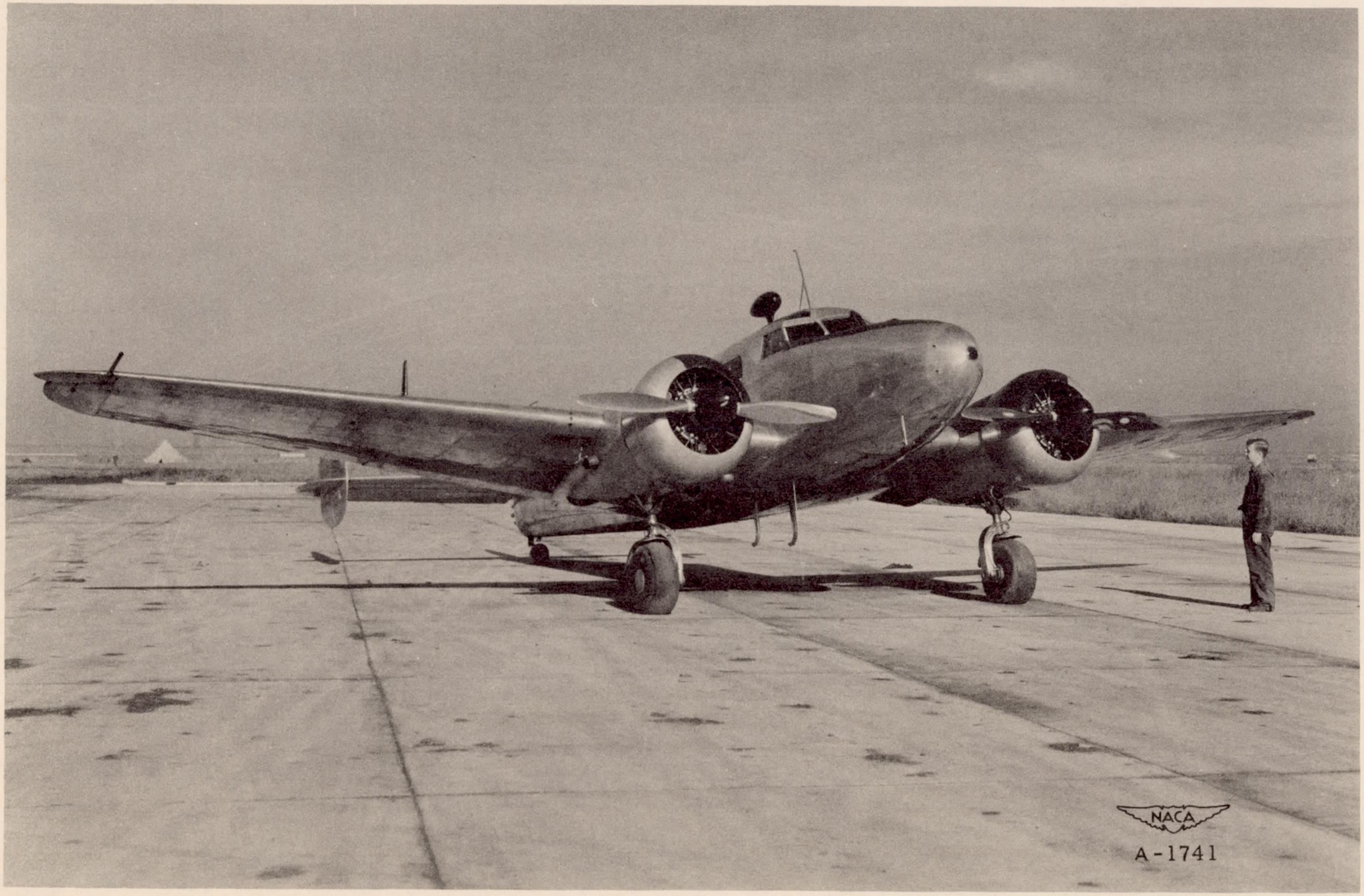


Figure 1.- The test airplane equipped with the exhaust-gas-air-mixture thermal ice-prevention system in the right wing.

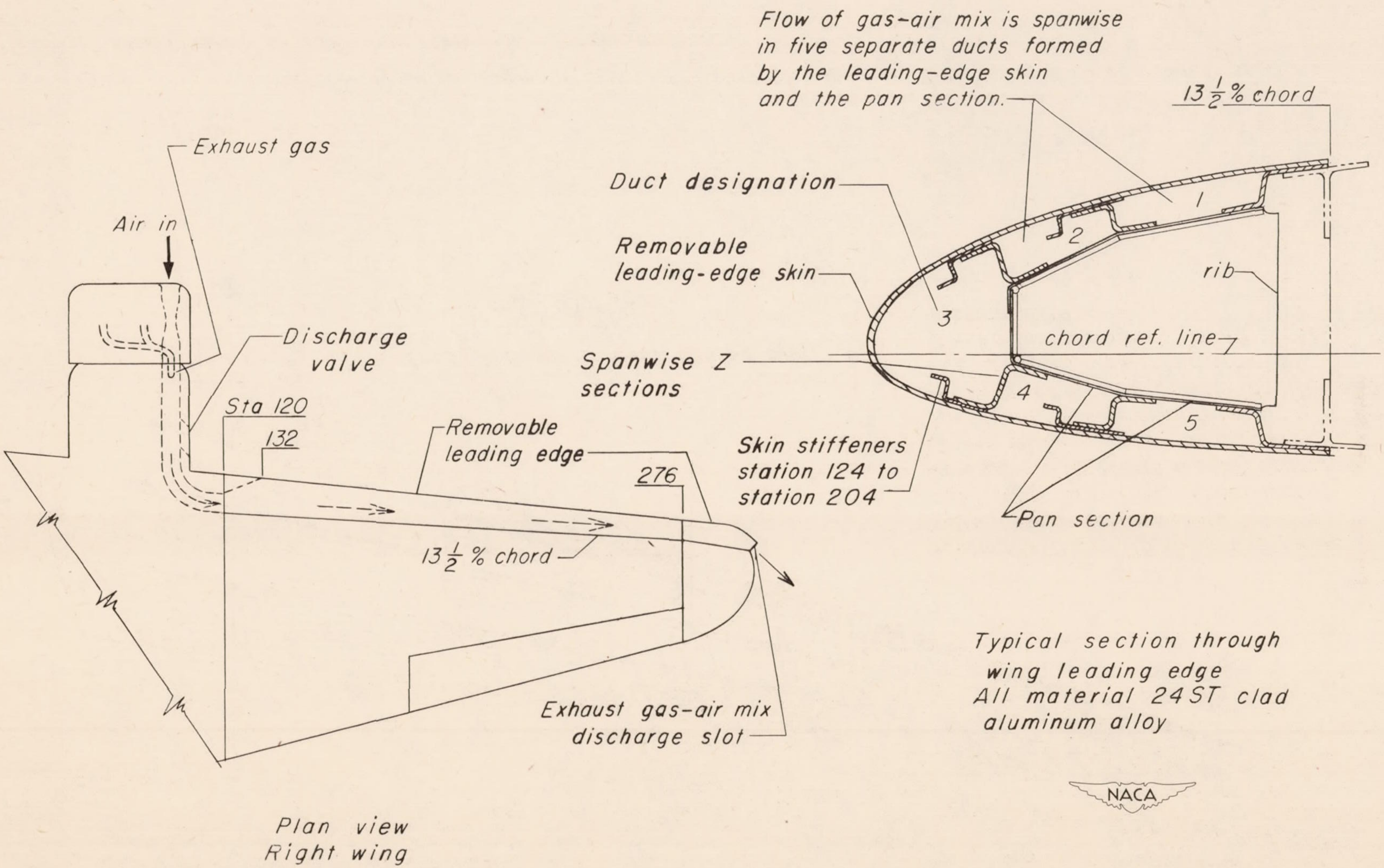


Figure 2.- Design details of the spanwise-flow exhaust-gas-air-mixture wing.

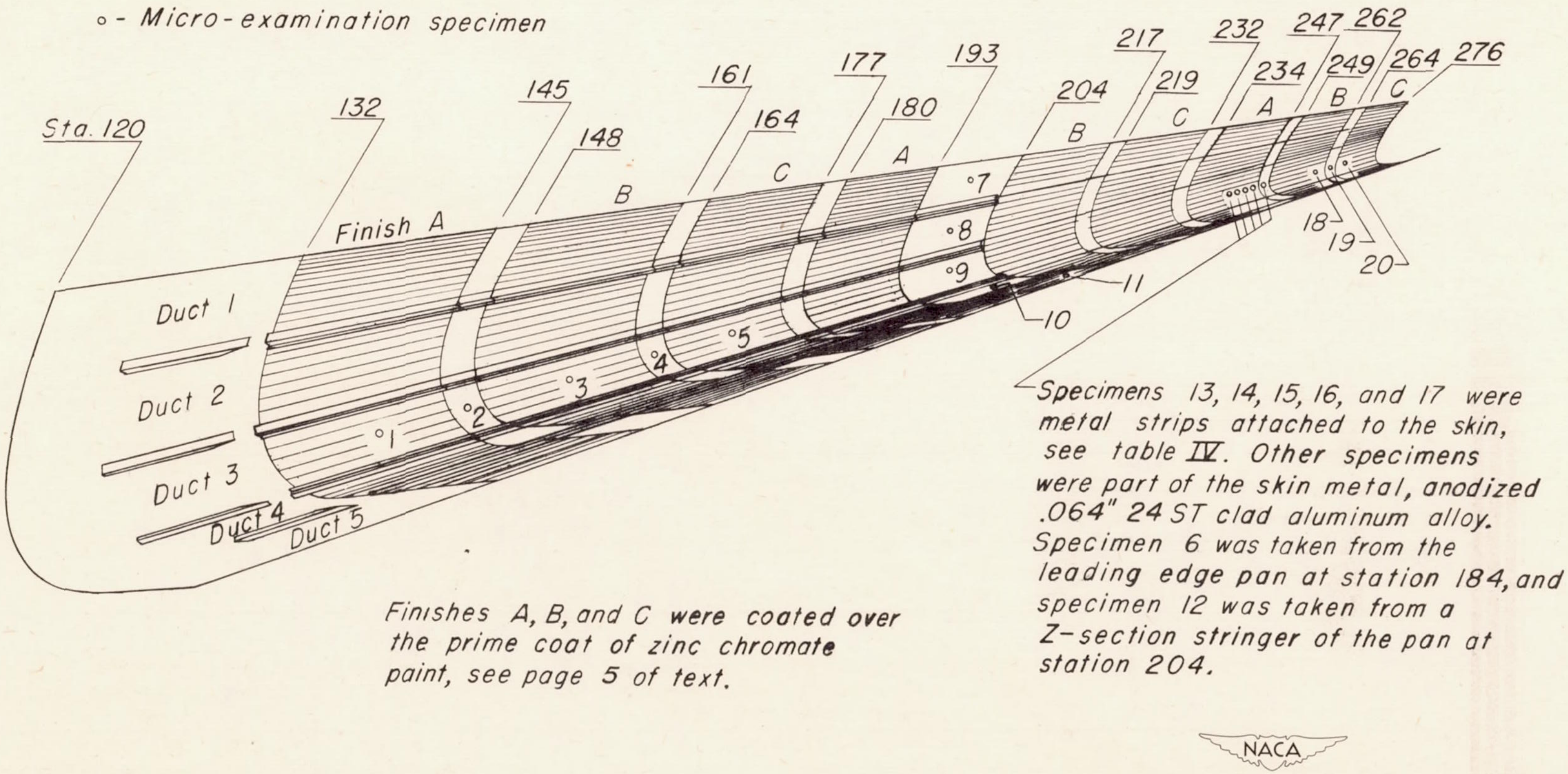


Figure 3.- Inner surface of the leading-edge skin of the exhaust-gas-air-mixture wing showing painted sections and location of specimens taken for micro-examination.

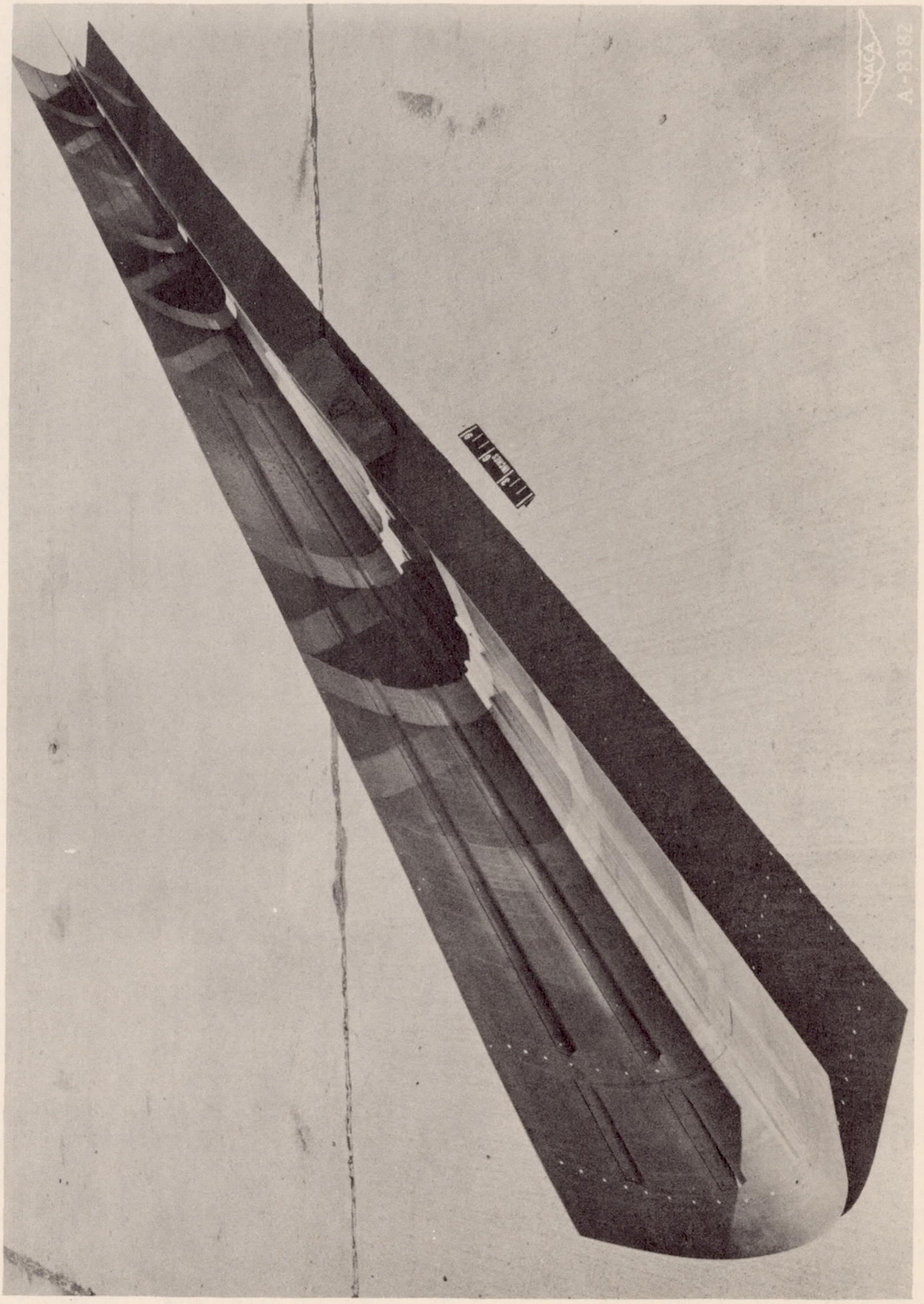


Figure 4.- Leading-edge skin of exhaust-gas-air-mixture wing.

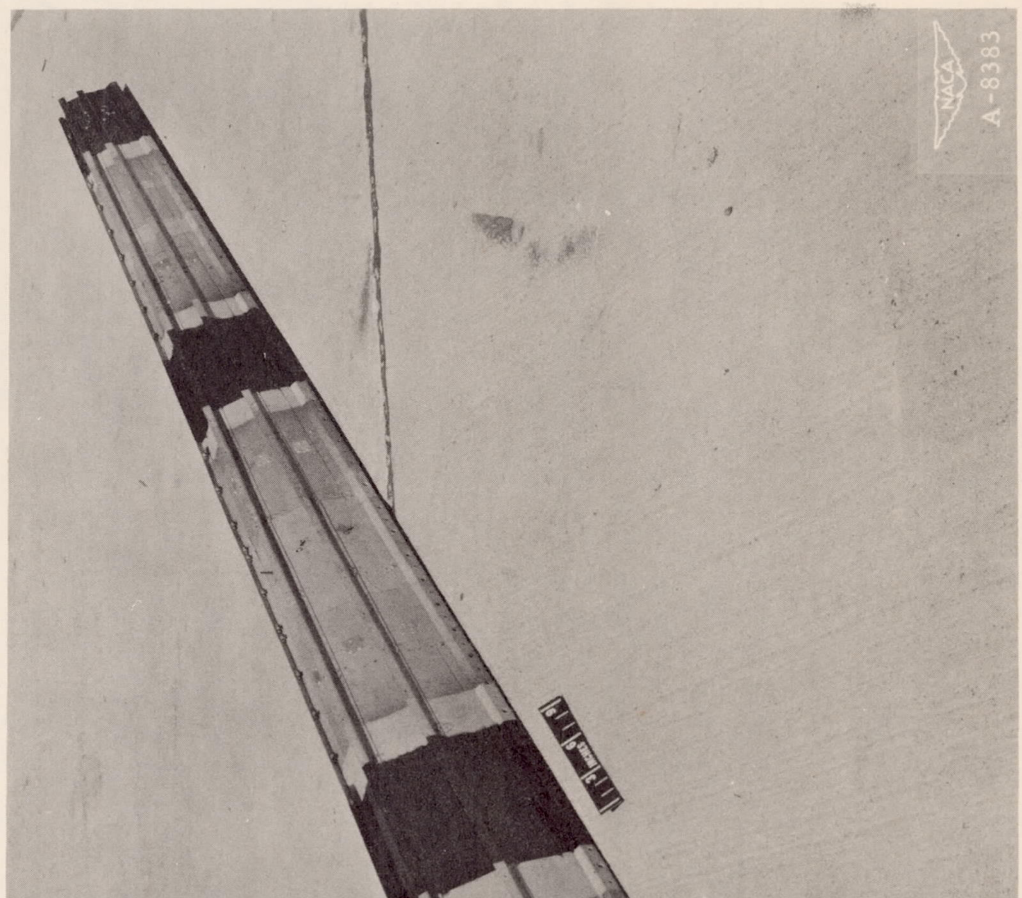


Figure 5.- Leading-edge pan of exhaust-gas-air-mixture wing.

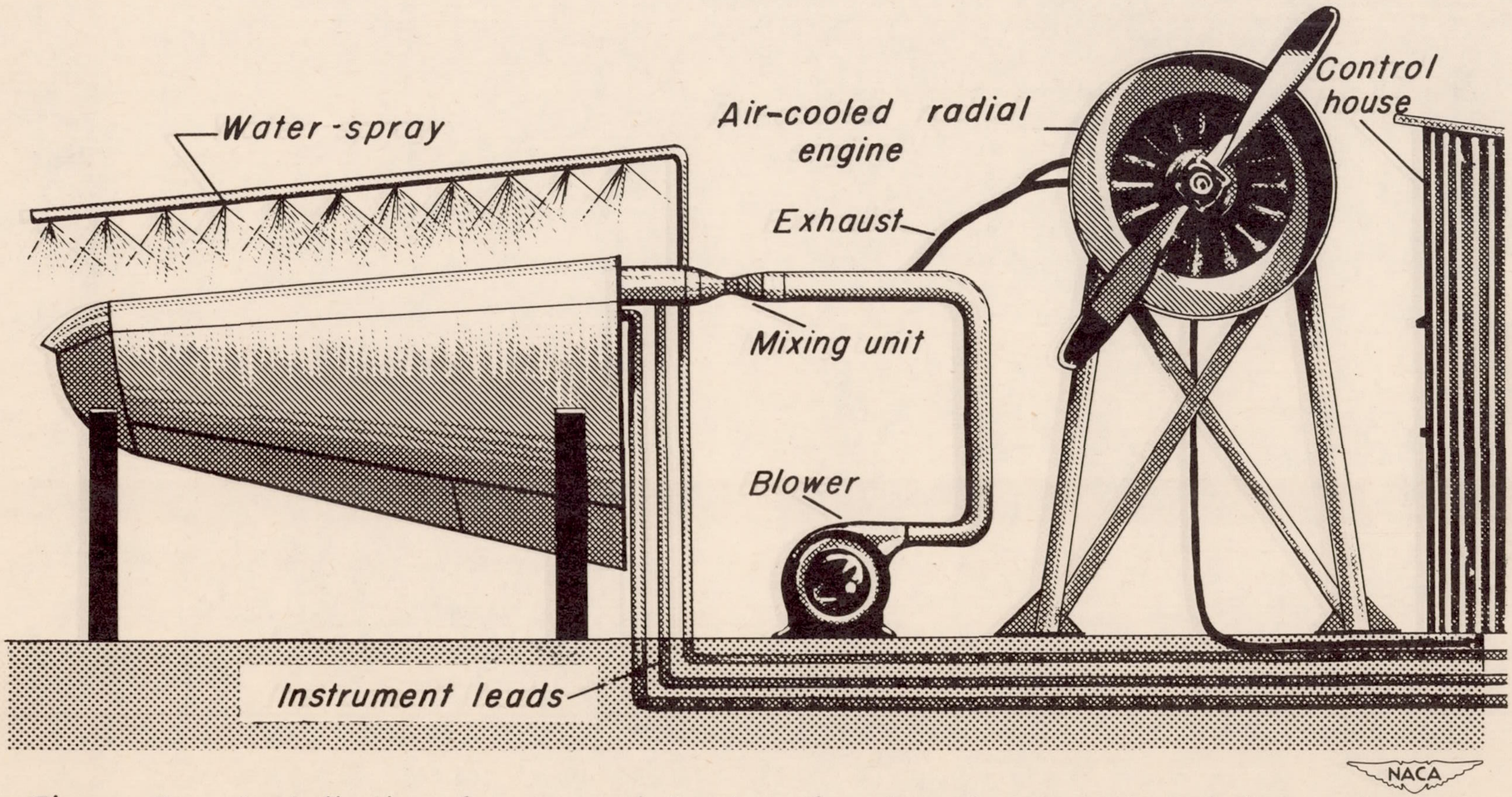


Figure 6.– Installation for ground tests of exhaust-gas-air-mixture wing.

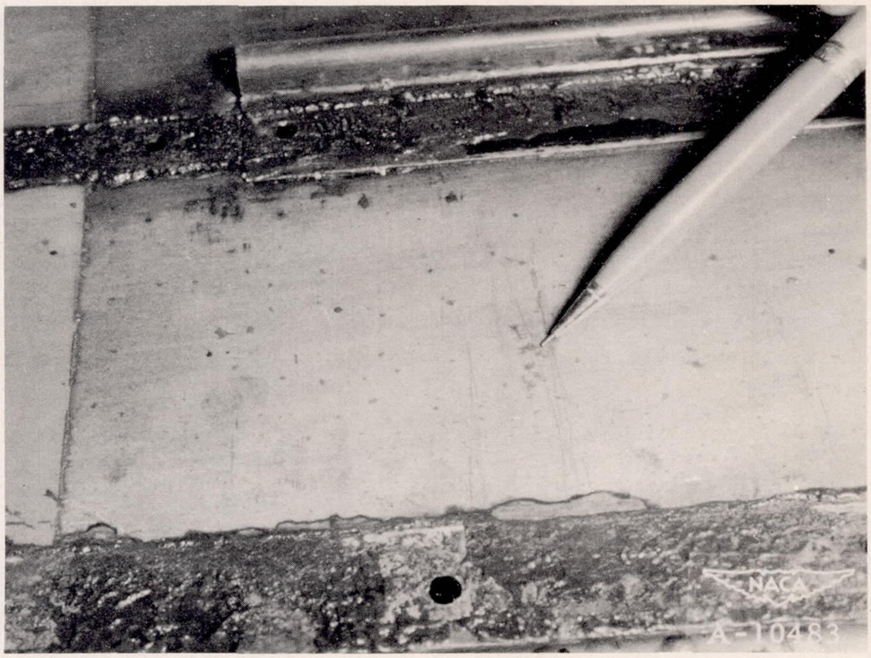
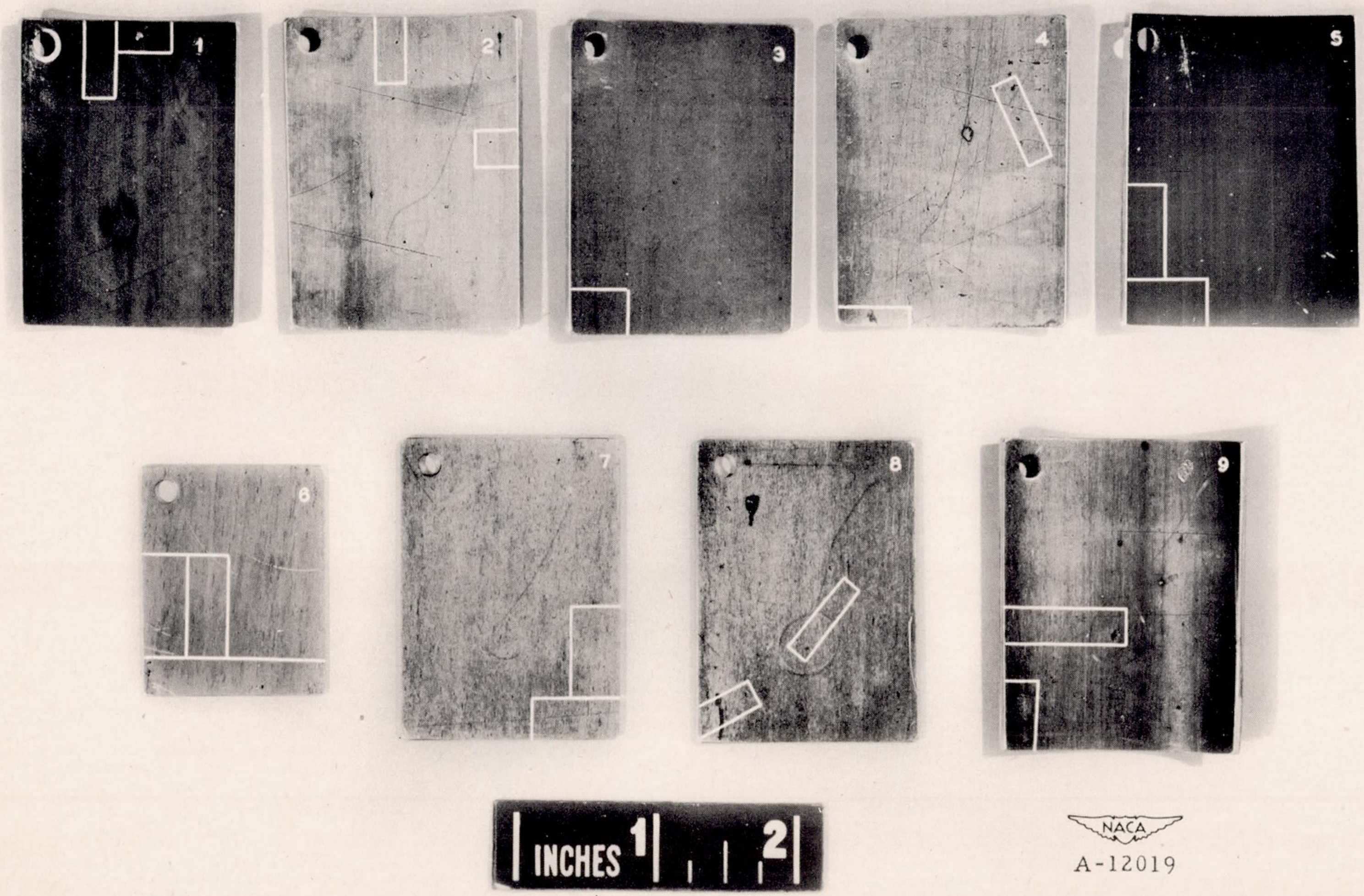
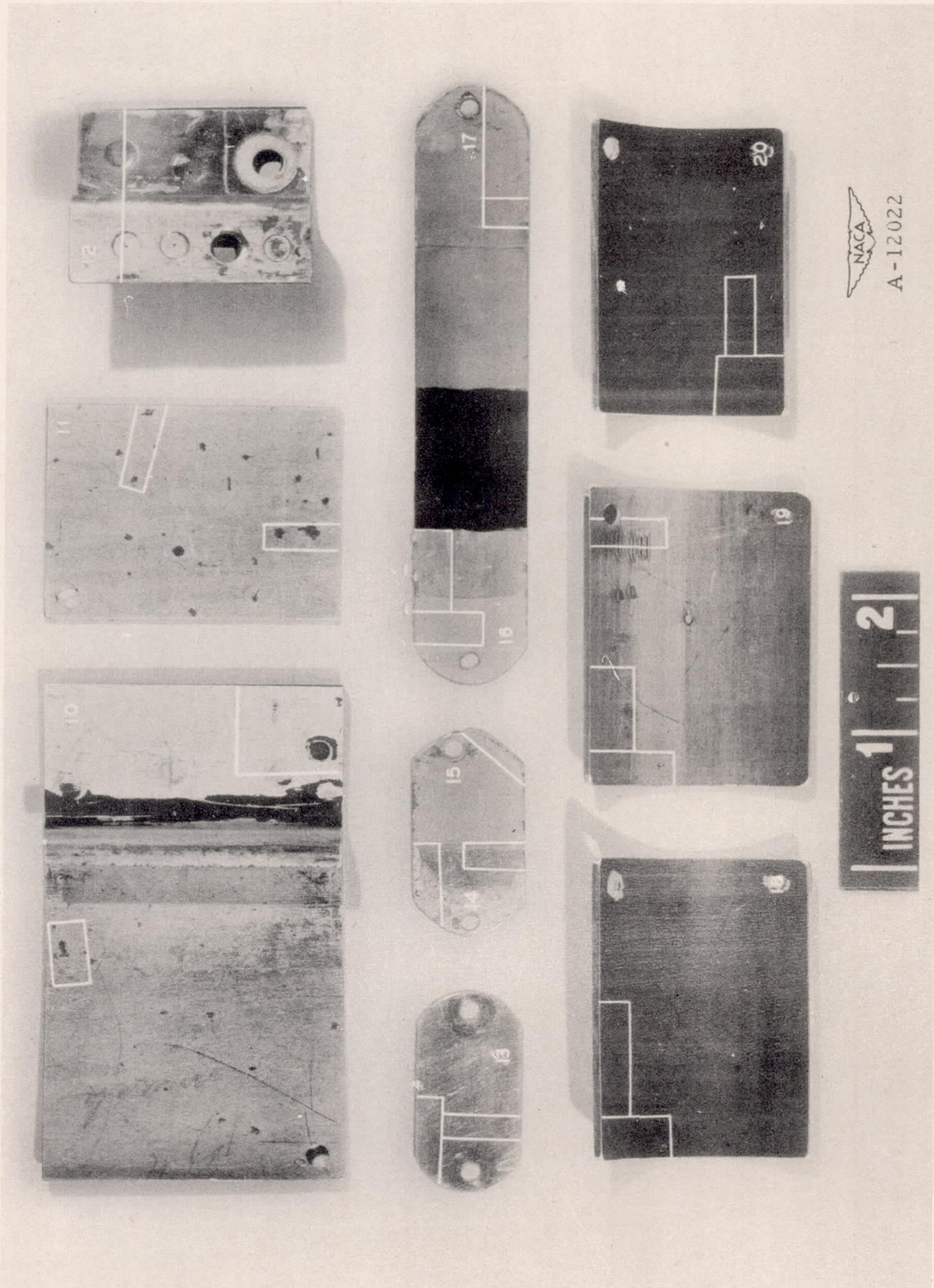


Figure 7.– Corrosion splotches on the inner surface of the leading–edge skin of the exhaust–gas–air–mixture wing after the completion of flight and ground tests. Spanwise duct 5; wing station 200.



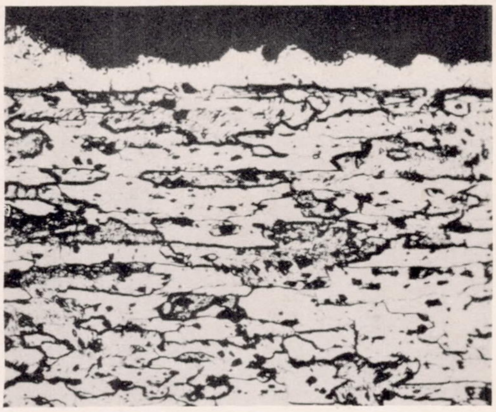
(a) Specimens 1 to 9.

Figure 8.- Specimens selected for metallurgical examination from the exhaust-gas-air-mixture wing. Sections indicated by white lines were examined microscopically by the National Bureau of Standards.

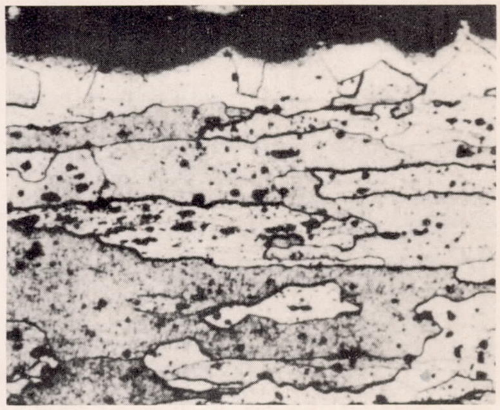


(b) Specimens 10 to 20.

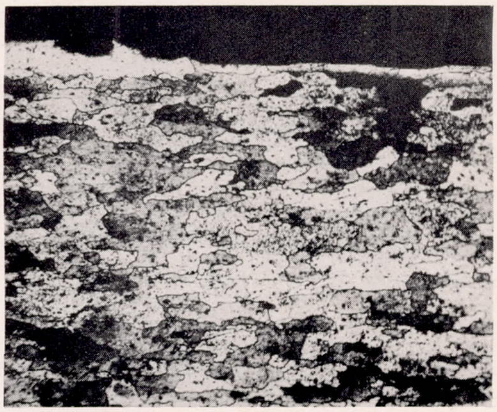
Figure 8.- Concluded.



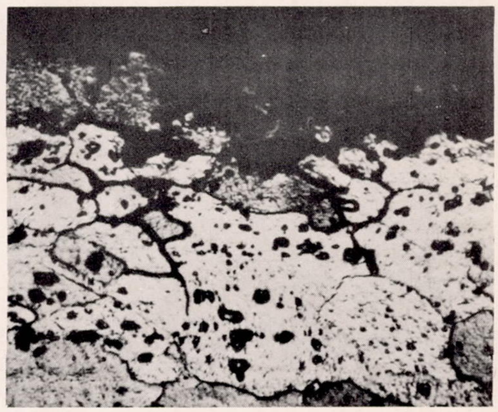
(a) Cross section through 1/16-inch-diameter splotch on specimen 4. About half the thickness of the clad layer was removed by corrosive attack. Magnification, 100X.



(b) Cross section of specimen 7 showing diffusion of core material into clad layer. Typical of all specimens from 7 to 20 except 13. Magnification, 200X.



(c) Cross section of specimen 11 showing corrosive attack had penetrated to the diffusion layer. Typical of attack on specimens 11, 16, 18. Magnification, 100X.



(d) Trace of intergranular corrosion at the bottom of a pit in specimen 13, bare 24ST, aluminum alloy. Magnification, 500X.

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Figure 9.- Typical photographs by the National Bureau of Standards of polished and etched sections taken from the exhaust-gas-air-mixture wing. Etchant: aqueous solution contining 2.5 percent HNO_3, 1.5 percent HCl, and 0.5 percent HF.