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SUMMARY

An exploratory low-speed wind tunnel test has been conducted in the Langley low-turbulence pressure tunnel to evaluate the concept of applying a thin plastic coating on an aircraft wing panel as one method of reducing drag due to surface roughnesses or excrescences such as steps, gaps, improperly seated fasteners, leaks, etc. The test was conducted at a Mach number of 0.15 and an angle-of-attack of 0°. The chord Reynolds number was varied from about 7×10^{6} to 63×10^{6}.

The results at the lowest Reynolds number indicate that coating the wing-panel decreased the profile drag coefficient to approximately that for an aerodynamically smooth NACA 6-series laminar flow airfoil. At Reynolds numbers sufficiently high to insure essentially full chord turbulent boundary layers a reduction of about 12-percent was measured. Other types of wing sections and construction methods should be investigated to establish the useful range of profile drag reduction by film coatings.

INTRODUCTION

Research on drag reduction has received considerable attention recently at the Langley Research Center because of the limited supply of petroleum fuels coupled with increasing energy demands. An excellent overview of several concepts for aircraft drag reduction is reported in reference 1. The roughness drag of an aircraft represents a small but important source of drag which can add appreciably to total aircraft drag and therefore to total fuel consumption. One approach to reduce the roughness or excresence drag caused by projecting or countersunk fasteners, steps, ridges, gaps and protuberances is to bond a thin plastic film to the aircraft skin. Since the wing represents a substantial proportion of the wetted area of an aircraft, a section of a T-33 wing was made available by the USAF so that an exploratory investigation could be performed to evaluate this approach.

The investigation was performed on a large chord (about 2 meters or 7-feet) wing-panel in the Langley low-turbulence pressure tunnel at a Mach number of 0.15 for a fixed angle-of-attack of 0^{o}, which is near the design lift coefficient for the airfoil. The chord Reynolds number was varied from about 7×10^{6} to 63×10^{6}.

SYMBOLS

Values are given in both the International System of Units (SI) and U.S. Customary Units.

c_d	section profile-drag coefficient, $\int_{wake} c_d' \, d(z/c)$
c_d'	point drag coefficient (ref. 4)
z	vertical distance in wake profile, cm (in.)
M	free stream Mach number
R	Reynolds number based on free-stream conditions and airfoil chord
c	Model chord length at drag measurement station 220.03 cm (86.625 in.)

MODELS, APPARATUS, AND PROCEDURE

Models

As received.- The model airfoil section was a NACA 65_1-213 (a = 0.5) low drag "laminar flow" section which was obtained by cutting a large chord segment from the wing of a T-33 aircraft. The wing, which incorporated some twist, taper, and dihedral had a constant airfoil section along the span with zero sweep of the 52-percent chord station. The aileron and simple split flap were attached with piano-type hinges. For the purpose of this test, the flap was securely fastened in a retracted position and a segment was cut from between two left-hand wing spanwise stations to obtain a large chord panel of about 83.82 cm (33 in.) in span. This section, or panel was typical of the entire wing and exhibited excrescences and surface roughness sufficient in number and type to be potentially useful for this exploratory test. The internal structure was reinforced with beams to provide for attachment to the tunnel walls and contoured wooden end-fairing blocks were installed between the ends of the model and the tunnel walls. The panel is shown in figure 1(a) mounted in the wind tunnel. A photograph of the wing panel "as received" but in preparation for installation in the tunnel is shown in figure 2(a).

Coated.- The coated model was achieved by cleaning the "as received" model and covering it with a thin plastic-type film applied over an adhesive substrate. Because of the concave surface curvature over the aft-portion of the model, it was necessary to apply the plastic film in three sections; the forward section was covered with continuous unbroken film coverage from about 75-percent chord on the upper to about 75-percent chord on the lower surface, and the remaining aft portions were covered as a separate application.

The model was prepared for coating by stripping the paint with a liquid paint remover followed by a rinse with cold water and dry air. The surfaces were then wet sanded and cleaned with Acetone. An Alodine solution was brushed on the surfaces to produce a uniform coating. This was followed by a cold water rinse and drying with air. This surface condition was allowed to age at least twenty-four hours before applying any adhesive substrate.

The thin (5-mils thickness) plastic film was applied under tension over a urethane adhesive which had been spread over the complete upper and lower surface while the adhesive was in a "fluid state". The application resulted in the flow of the adhesive, before setting, so that small deformations, protuberances, joints, gaps and steps were sealed and faired smooth. A schematic representation of the film covering representative roughnesses and excrescences is shown in figure 3.

The forward section of the thin plastic film was stretched over the airfoil from 0.75c over the upper surface, around the leading-edge, and over the lower to 0.75c. The long spanwise joints near 0.75c, in the region of flap attachment, were internally partially back-filled with a hardened filler to prevent fluid adhesive from flowing through the unsealed region. Tension was applied to the ends of the film by means of wood strips to force conformance of the film to the contour of the surfaces. External pressure was applied to the film with hand squeegies to force out air bubbles toward the open edges of the plastic sheet and thin out the substrate filler. At about 0.75c, on both surfaces, the plastic film was made to overlap over another, or second, section of film previously applied that extended to near the trailing edge. The spanwise overlapping joint between film sections constituted a rear facing feather edge which provided an aerodynamically smooth seam. This second section of plastic film was made to conform to the surface contour over the remaining 0.25c to within about 3 cm (1 in.) of the trailing edge. The covered model was allowed to cure for at least 48 hours and the plastic was trimmed to shape.

The first attempt to coat the model with the urethane adhesive met with numerous unexpected problems and resulted in large unbonded regions, especially on the forward 0.75c upper and lower coated regions. The aft coated 0.25c region was deemed acceptable for testing. It was difficult to apply the large regions of the urethane substrate uniformly before the "pot life" or gelling became critical with respect to properly tensioning the plastic uniformly and working the squeegies. Also, the resin and hardener were sensitive to temperature and humidity, which could not be well controlled for this application. Because the resulting surface was unsatisfactory it was necessary to remove the forward 0.75c upper and lower coating and substrate.

A second and successful attempt was made to cover the model using an epoxy casting resin as the substrate adhesive that provided a longer "pot life" and was not as sensitive to temperature and humidity. This resin was selected because of excellent previous experience in the same environment on similiar applications. A photograph of the resulting coated model is shown in figure 2(b).

Wind Tunnel

The Langley low-turbulence pressure tunnel (ref. 2) is a closed-throat, single return tunnel which can be operated at stagnation pressures from 1 to 10 atmospheres with tunnel-empty test-section Mach numbers up to 0.42 and 0.22, respectively. The maximum unit Reynolds number is about 49×10^6 per meter (15×10^6 per foot) at a Mach number of about 0.22. The tunnel test section is 91.44 cm (3 ft) wide by 228.6 cm (7.5 ft) high.

Wake Survey Rake

A fixed wake-survey rake was ioned about 0.35c rearward of the model trailing-edge and approximately at t tunnel center line where the model chord was 220.03 cm (86.625 in.) as shown in figure 1(a). The wake measurement rake consisted of a row of total-pressure tubes closely spaced vertically within the expected region of the model wake and static-pressure tubes laterall displaced.

The rake was attached to the center line sting mount in the tunnel, which was used to vertically position the rake within the wake so that the center of the wake was measured by the closely spaced tubes. The wake rake employed 47 total-pressure tubes 0.152 cm (0.060 in.) in diameter and 3 static-pressure tubes 0.318 cm (0.125 in.) in diameter. The total-pressure tubes were flattened horizontally for a distance of 0.61 cm (0.24 in.) from the tip of the tube to a height of 0.102 cm (0.040 in.) and each static-pressure tube had 4 flush orifices located 90^{0} apart, 8 tube diameters from the tip of the tube in the measurement plane of the total-pressure tubes. The rake is shown in figure 1(b).

Instrumentation

Measurements of the wake rake pressures were made by an automatic pressure-scanning system utilizing variable capacitance precision transducers. Basic tunnel pressures were measured with precision quartz manometers. Data were obtained by a high-speed data acquisition system and were recorded on magnetic tape.

TEST AND METHODS

The airfoil was installed with the chord line fixed at an angle-of-attack of 0^{0} in order that the profile drag could be measured in a region of minimum drag near the design lift coefficient. The test was conducted at a Mach number of about 0.15 and the Reynolds number, based on the airfoil chord, was varied from about 7.3×10^6 to 63.3×10^6. The model was tested "as received" and then removed from the wind tunnel and coated with the thin plastic film. The coated model was then re-installed and tested.

In order to establish the turbulent skin friction drag level for the coated model at the lowest test Reynolds number, $R \approx 7 \times 10^6$, transition grit strips were installed on the upper and lower model surfaces at the 5-percent chordwise station. The grit was sized for the Reynolds number according to reference 3 and the strips were 0.318 cm (0.125 in.) wide over the airfoil span. The grains were sparsely spaced and attached to the plastic film with clear lacquer.

Section profile-drag coefficients were computed from the measured wake-rake total and wake-rake static pressures by the method of reference 4. Since the primary objective of this test was to obtain incremental drag values resulting from application of the surface coating, no low-speed wind-tunnel boundary corrections have been applied to the data. It should also be recognized that a large chord model such as the present wing-panel is too large for this wind tunnel and absolute values of the drag coefficient are subject to small errors. However, past research in this wind tunnel, at 0^o or low lift coefficients (ref. 5), has shown that profile drag measurements obtained on large chord models were very close to those with models more appropriately sized.

DISCUSSION OF RESULTS

The surface roughness and fairness of various practical construction wing sections has been improved in the past by surface improvement procedures such as reported in references 5 and 6. The drag data were presented for model surface conditions "as received" and "after surface finishing". These results showed that by suitable procedures the drag could be reduced to approach the drag levels of aerodynamically smooth models of corresponding sections, at least for Reynolds numbers up to 20 x 10^6.

The variation of profile drag coefficient with Reynolds number obtained in this investigation is shown in figure 4 for the model "as received" and "coated". The drag level of the model "as received" is generally consistent with the data for the "practical construction" 6-series airfoils reported in references 5 and 6. The application of a thin plastic-type coating reduced the profile drag coefficient at all test Reynolds numbers. At about R = 7 x 10^6, the drag coefficient was reduced about 40-percent and approached the drag levels expected for smooth 6-series airfoils with long runs of laminar flow (ref. 5). Increasing the Reynolds number for the coated model resulted in a gradual increase in the drag coefficient up to about R = 35 x 10^6. This increase in c_d is a result of the forward movement of the boundary-layer transition point (ref. 7). Several factors certainly affect the Reynolds number at which the forward movement occurs such as model surface roughness, waviness, and wind-tunnel turbulence level. It is believed that an increasing turbulence level with increasing Reynolds number in this tunnel was largely responsible for this forward movement. Essentially full chord turbulent flow is believed to have existed on the coated model for Reynolds numbers greater than about R = 35 x 10^6. This result is supported by the drag data presented for this same airfoil section with a smaller chord of 60.63 cm (23.87 in.) with fixed transition near the leading-edge (ref. 8). Extrapolation of the data for the smaller chord model to higher Reynolds numbers indicates that the drag level approaches that for the large chord coated model. A decrease in drag coefficient of about 12-percent is shown for the coated model for Reynolds numbers greater than about R = 35 x 10^6.

One data point was obtained at about R = 7 x 10^6 for the coated model with transition fixed at 5-percent chord. The drag level is essentially the same as that for the "as received" model and the data indicate that the drag coefficient is approximately the same as for the smaller chord smooth model with fixed transition. This result suggests that little or no benefit in drag reduction would be gained at this or any lower Reynolds number on coated panels constructed similar to this "as received" model when the entire boundary layer is turbulent.

CONCLUDING REMARKS

An exploratory low-speed wind tunnel test has been conducted in the Langley low turbulence pressure tunnel to evaluate the concept of applying a thin plastic coating on an aircraft wing-panel as one method of reducing drag due to surface roughness or excrescences such as steps, gaps, improperly seated fasteners, leaks, etc. The test was conducted at a Mach number of 0.15 and an angle-of-attack of 0^o. The chord Reynolds number was varied from about 7 x 10^6 to 63 x 10^6.

The results at the lowest Reynolds number indicate that coating the wing-panel decreased the profile drag coefficient to approximately that for an aerodynamically smooth NACA 6-series laminar flow airfoil. At Reynolds numbers sufficiently high to insure essentially full chord turbulent boundary layers a reduction of about 12-percent was measured. Other types of wing sections and construction methods should be investigated to establish the useful range of profile drag reduction by film coatings.

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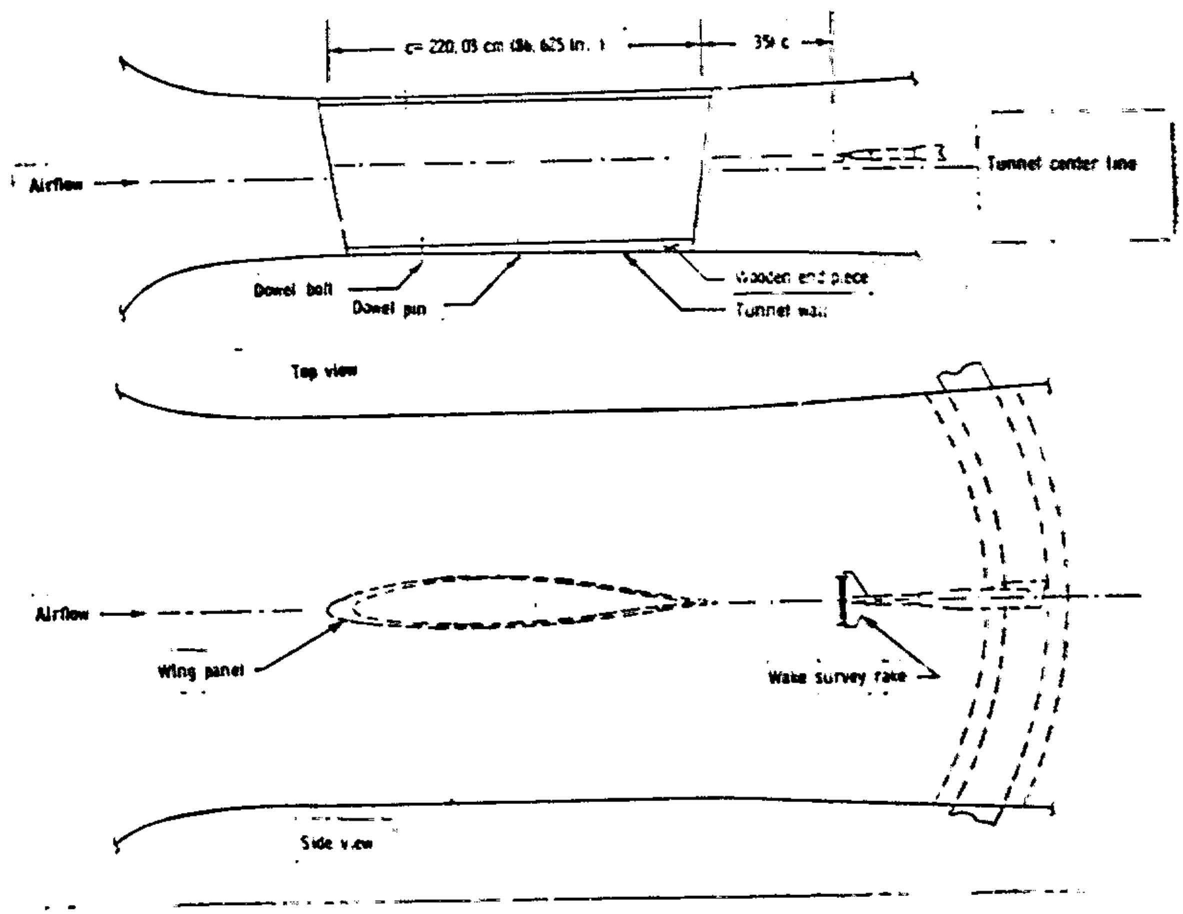
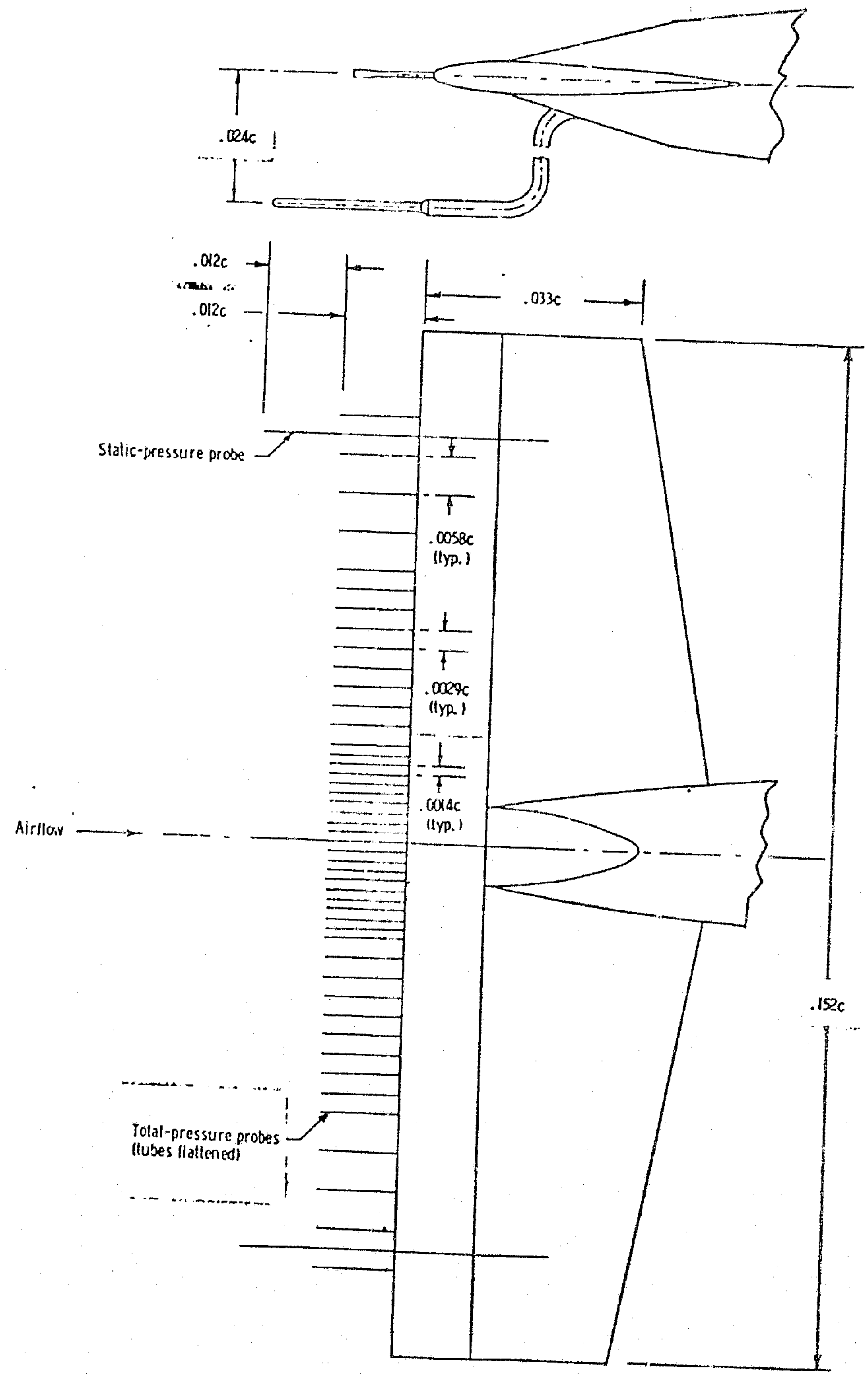


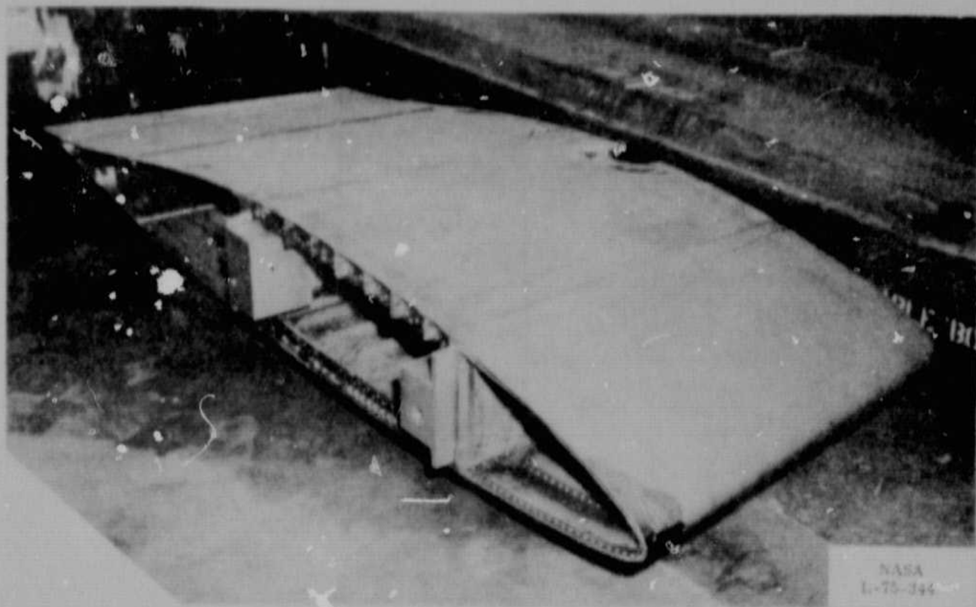
(a) Wing-panel mounted in tunnel.

Figure 1. - Apparatus.

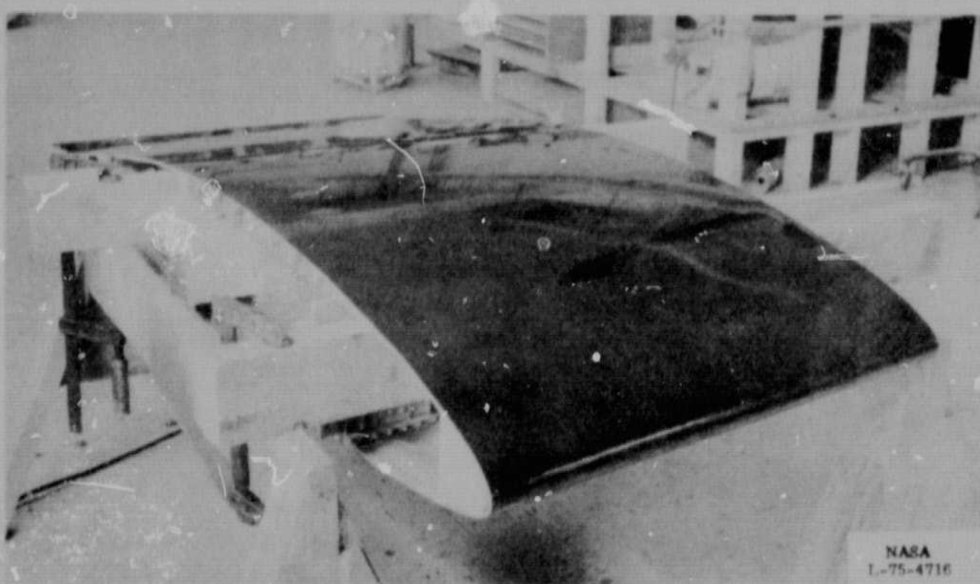


(b) Wake survey rake.

Figure 1.- Concluded.



(a) As received in preparation for tunnel installation.



(b) Coated with thin plastic cover.

Figure 2. - Photographs of wing-panel.

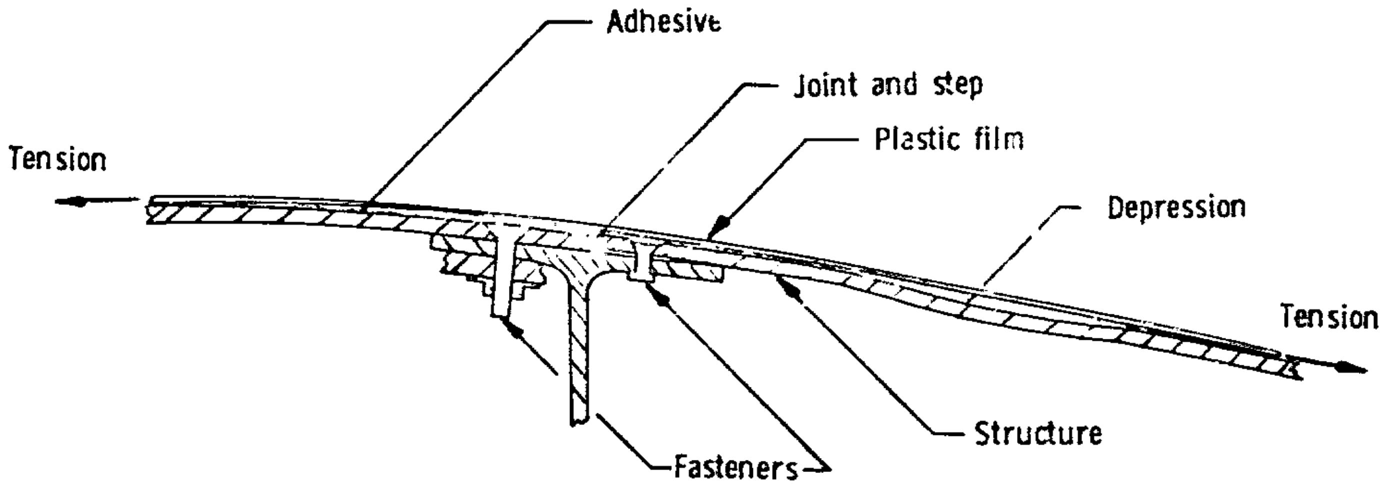


Figure 3.- Schematic representation of some surface irregularities covered by plastic film.

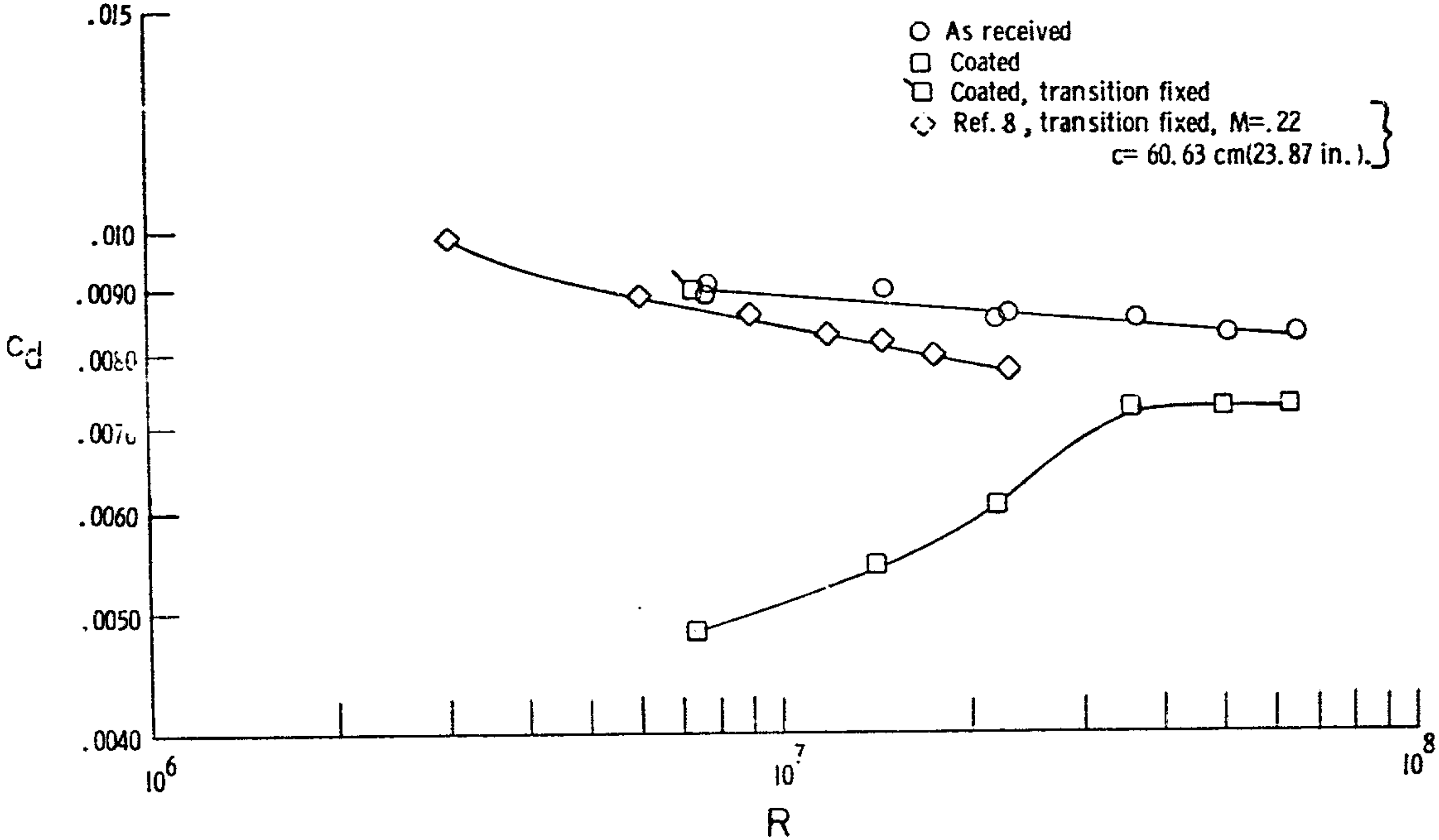


Figure 4. - Variation of profile drag coefficient with Reynolds number.

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16. Abstract
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