SURFACE FINISH MEASUREMENT STUDIES

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NASA and the National Bureau of Standards initiated a project in the fall of 1980 to address any potential new problems that might be imposed on the surface finish requirements for models to be used in the National Transonic Facility (NTF). At the largest Reynolds numbers of which the NTF was to be capable, admissible roughness heights fell below the surface finishes currently specified for models. The objective of the joint NASA/NBS project were therefore (1) to evaluate the performance of stylus instruments for measuring the topography of NTF model surfaces both for monitoring during fabrication and as an absolute measurement of topography, (2) to measure and characterize the true three-dimensional topography of NTF model surfaces so that their characteristics could be related back to distributed particle surfaces, and (3) to develop a prototype light-scattering instrument which would allow for rapid assessment of the surface finish of a model.

Work to accomplish the first objective has consisted of comparing research-grade and shop-grade stylus measurements of the surface finish of three test specimens fabricated by NASA. Conclusions from this study and the three-dimensional stylus profilometry developed at NBS for the second objective are that the shop-grade instruments can damage the surface of models and that their use for monitoring fabrication procedures can lead to surface finishes that are substantially out of range in critical areas of the leading edges.

Two closely related concerns were raised relative to the issue of surface finishes. First, in interpreting the classical work of Nikarudse (ref. 1), what properties of the surface topography influence the airflow pattern across a surface and what are the curves of allowed values for these new characterizations as a function of Reynolds number? The need for understanding both surface amplitude and wavelength effects was discussed. Second, in connection with the third objective, the capabilities of major surface topography measurement techniques were presented and compared in terms of a wavelength/slope space. The limited spatial wavelength bandwidth capabilities of light-scattering measurements were highlighted. In relation to the measurement needs for NTF model surfaces, it is therefore important, in using this technique or any other, to determine what range of irregularity spacings is of significance for aerodynamic effects.

REFERENCE

1. Schlichting, Hermann (J. Kestin, transl.): Boundary Layer Theory. Fourth ed., McGraw-Hill Book Co., Inc., c.1960.

QUESTIONS

HOW ACCURATELY DOES A STYLUS INSTRUMENT MEASURE THE TOPOGRAPHY OF A SPECIMEN?

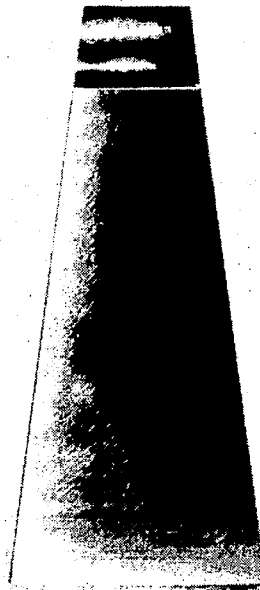WHAT ALTERNATIVES TO THE STYLUS ARE AVAILABLE?

WHAT PROPERTIES OF SURFACE TOPOGRAPHY INFLUENCE AN AIRFLOW PATTERN?

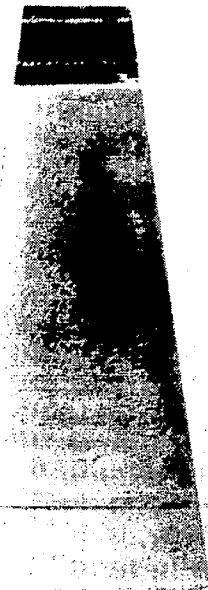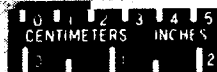WHAT PARAMETERS BEST CHARACTERIZE THESE PROPERTIES?

SURFACE FINISH SPECIMENS

LD-537179-2
4 to 6 Microinches

LD-537179-4
8 to 10 Microinches

LD-537179-6
12 to 15 Microinches
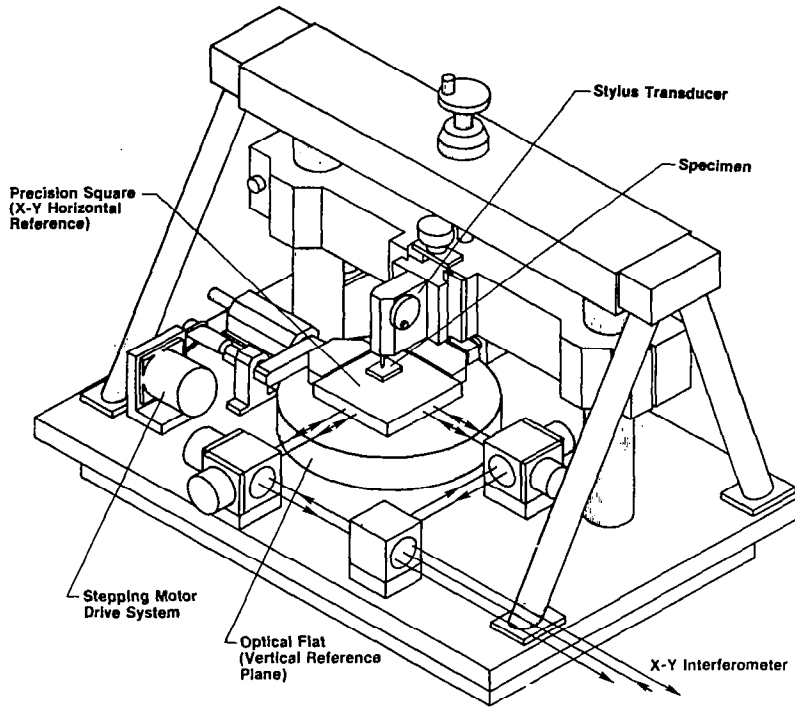
CENTIMETERS   INCHES

STYLUS MEASUREMENTS

- Finite Horizontal Resolution
- Potential Damage to Test Surface
- 2-D Sampling of Surface
- Slow and Difficult to Adapt to Curved Surfaces
- Detailed Quantitative Profile Output
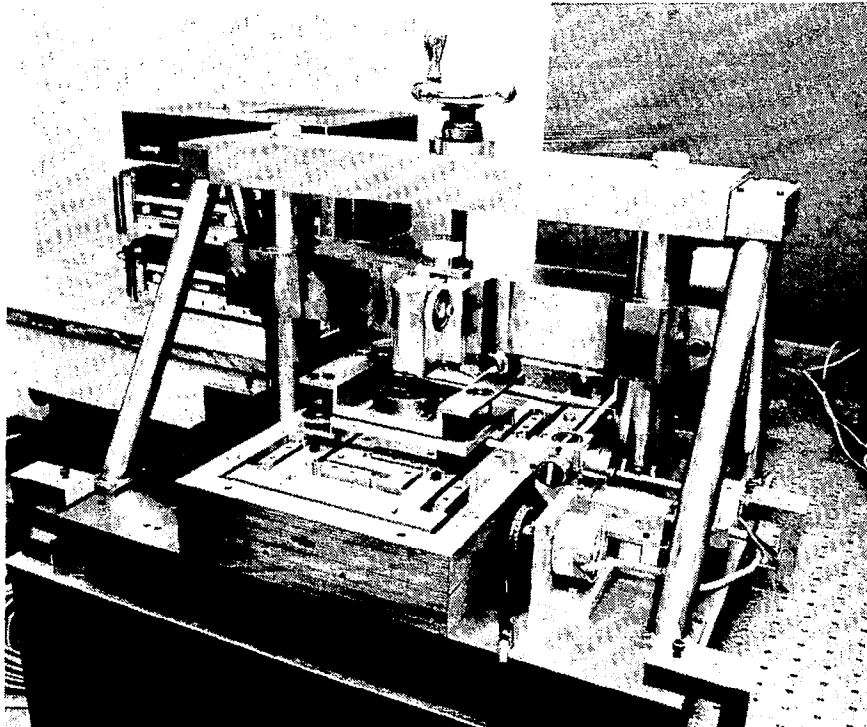- Combined Horizontal-Vertical Resolution Best of All Standard Techniques
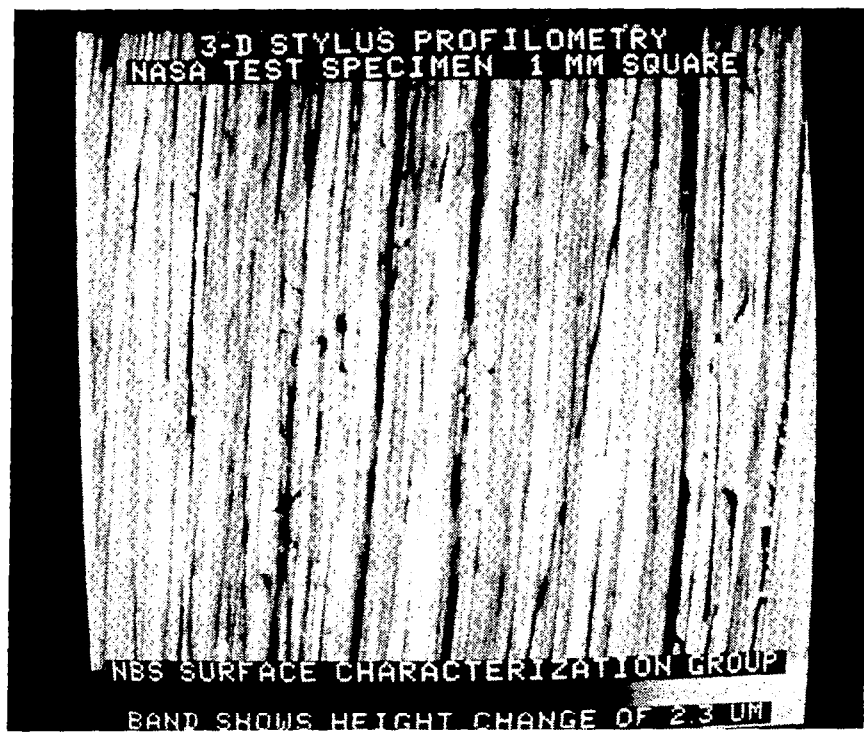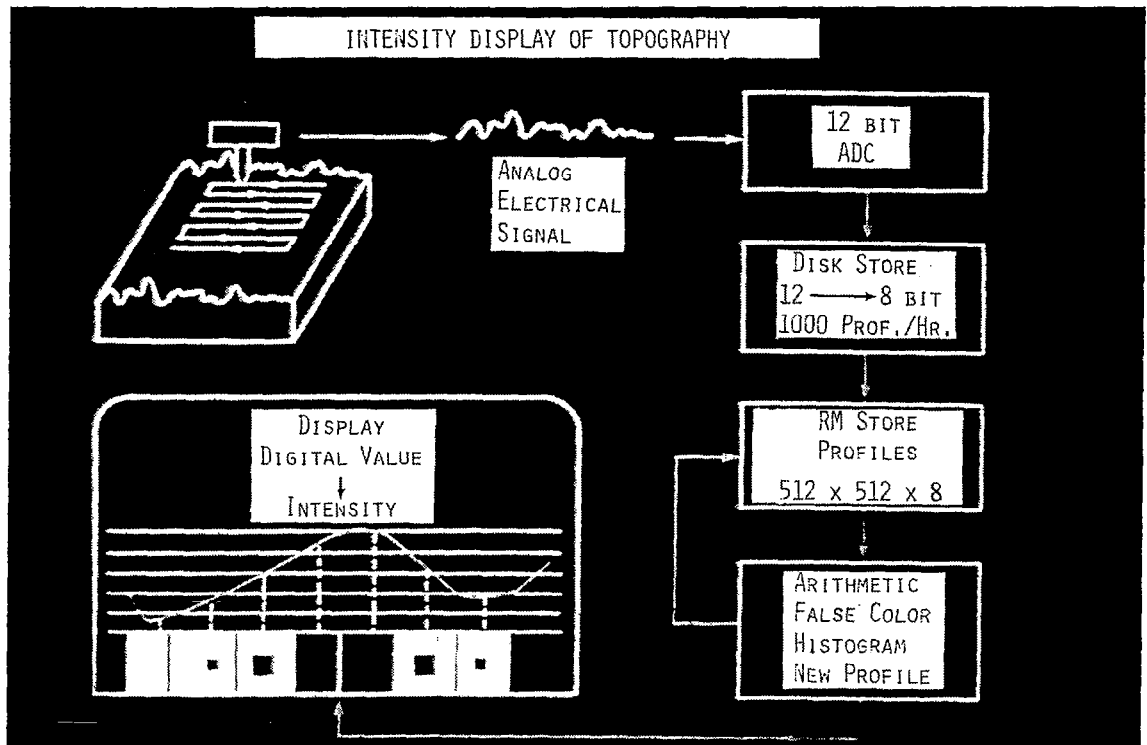
WORK TO OVERCOME LIMITATIONS

- 3-D Stylus Profilometry
- SEM Stereoscopy
- Light Scattering

SCHEMATIC OF TOPOGRAPHY MEASURING INSTRUMENT

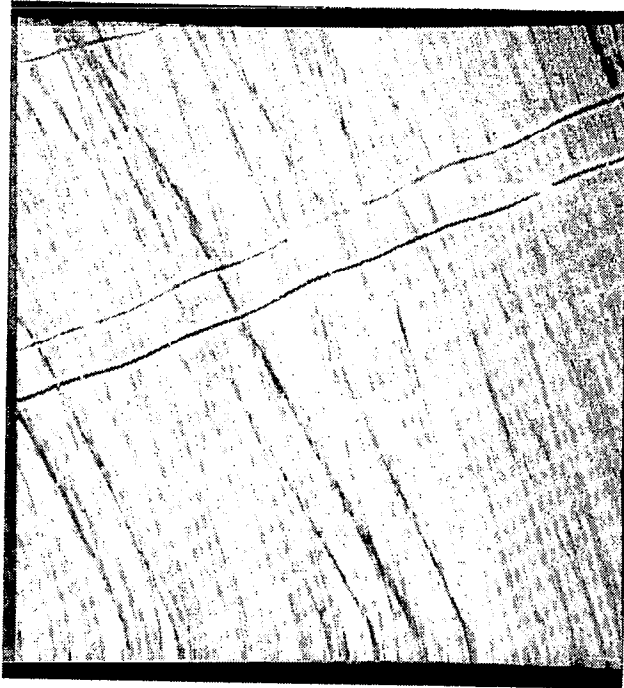Stylus Transducer

Specimen

Precision Square
(X-Y Horizontal
Reference)

Stepping Motor
Drive System

Optical Flat
(Vertical Reference
Plane)

X-Y Interferometer

TOPOGRAPHY MEASURING INSTRUMENT

INTENSITY DISPLAY OF TOPOGRAPHY

ANALOG ELECTRICAL SIGNAL

12 BIT ADC

DISK STORE
12 ⟶ 8 BIT
1000 PROF./HR.

RM STORE
PROFILES
512 x 512 x 8

ARITHMETIC
FALSE COLOR
HISTOGRAM
NEW PROFILE

DISPLAY
DIGITAL VALUE
↓
INTENSITY

3-D STYLUS PROFILOMETRY
NASA TEST SPECIMEN 1 MM SQUARE

NBS SURFACE CHARACTERIZATION GROUP

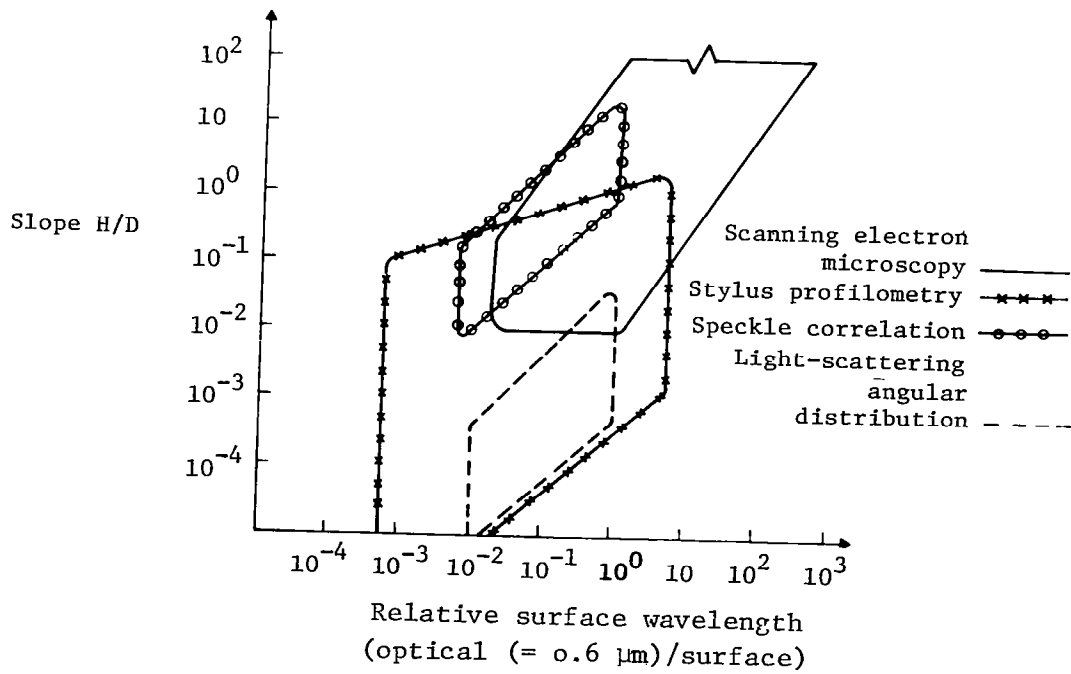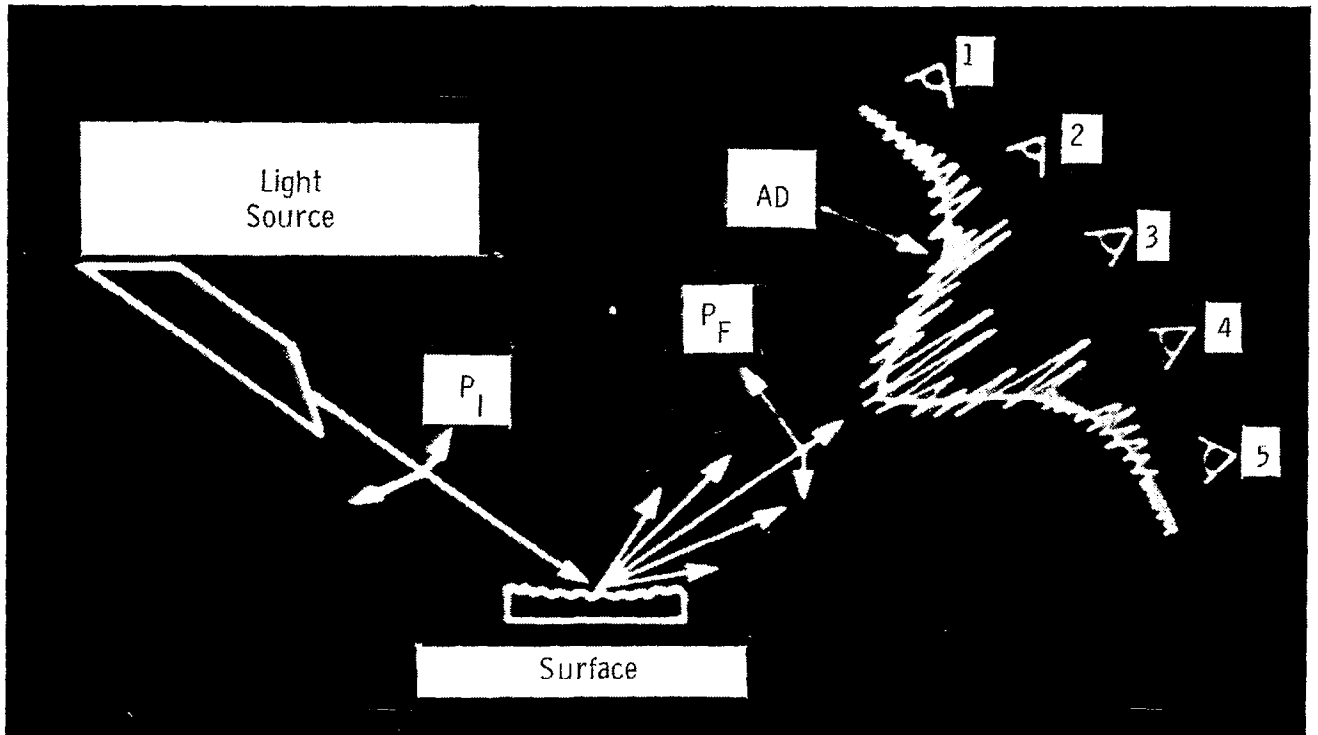BAND SHOWS HEIGHT CHANGE OF 2.3 UM

POTENTIAL STYLUS DAMAGE TO SPECIMEN

SENSITIVITY REGIONS FOR SURFACE MICROTOPOGRAPHY INSTRUMENTS

Slope H/D

Scanning electron microscopy ————
Stylus profilometry —✳—✳—✳—
Speckle correlation —o—o—o—
Light-scattering angular distribution — — — —

Relative surface wavelength
(optical (= o.6 μm)/surface)
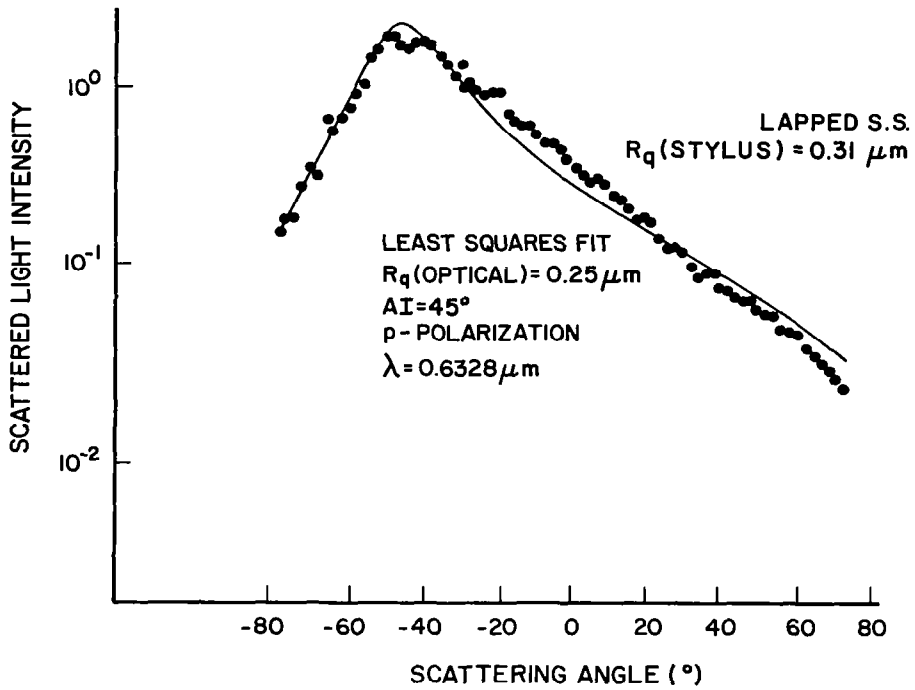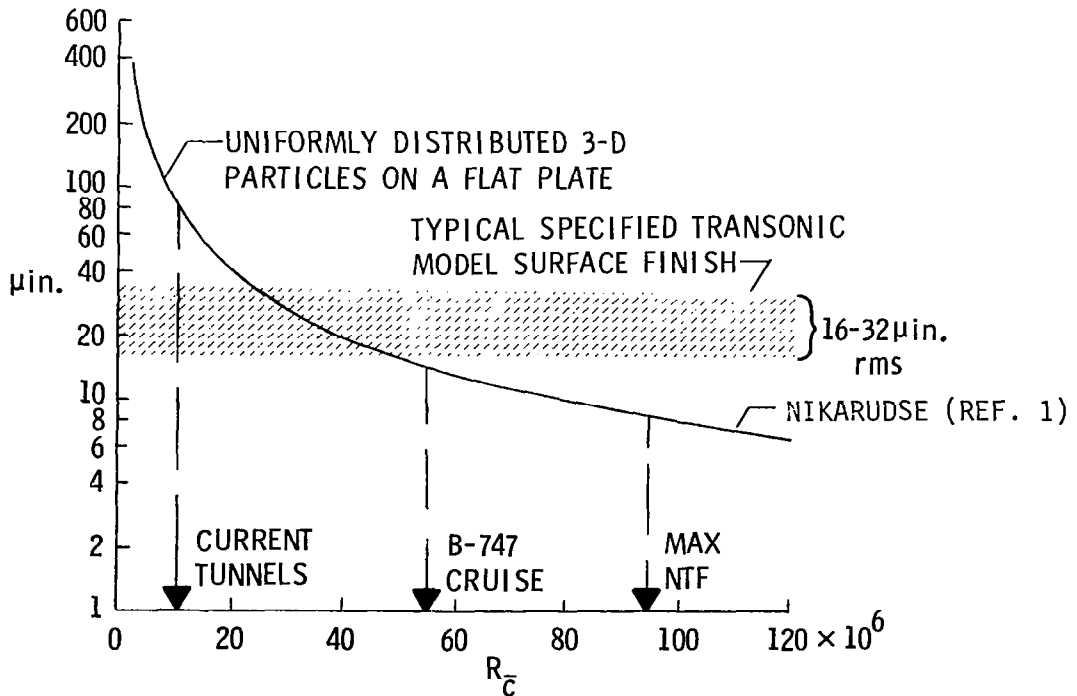
DETECTOR ARRAY FOR LASER LIGHT ANGULAR SCATTERING
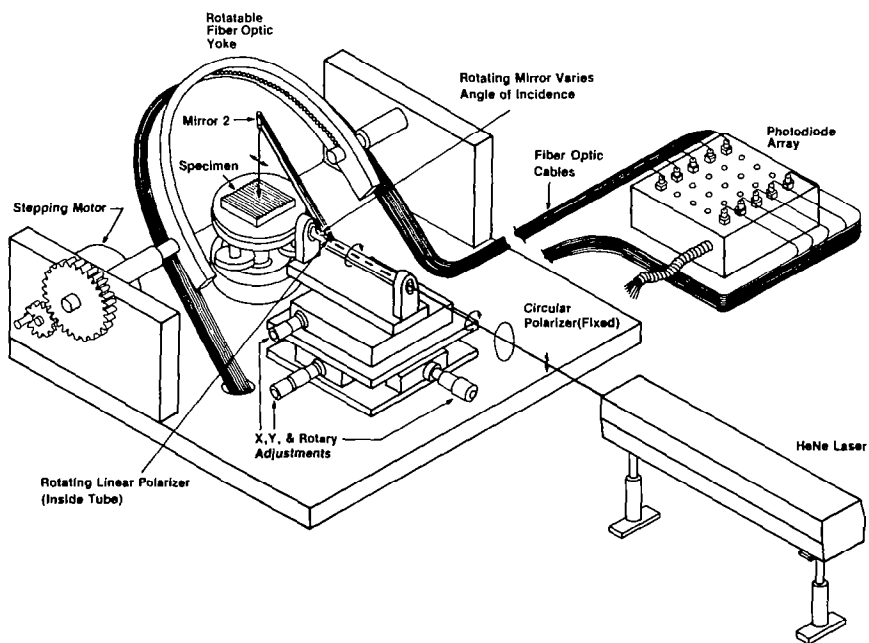
PRELIMINARY RESULTS - LIGHT SCATTERING
THEORY VERSUS EXPERIMENT

SCATTERED LIGHT INTENSITY

10^0

10^{-1}

10^{-2}

LAPPED S.S.
R_q (STYLUS) = 0.31 μm

LEAST SQUARES FIT
R_q (OPTICAL) = 0.25 μm
AI = 45°
p - POLARIZATION
λ = 0.6328 μm

-80 -60 -40 -20 0 20 40 60 80

SCATTERING ANGLE (°)

ACCEPTABLE ROUGHNESS FOR TYPICAL NTF MODEL
$\bar{c}$ = 0.20 m

600
400

200

100
80
60
40

20

10
8
6

4

2

1

μin.

—UNIFORMLY DISTRIBUTED 3-D
PARTICLES ON A FLAT PLATE

TYPICAL SPECIFIED TRANSONIC
MODEL SURFACE FINISH—7

16-32 μin.
rms

NIKARUDSE (REF. 1)

CURRENT
TUNNELS
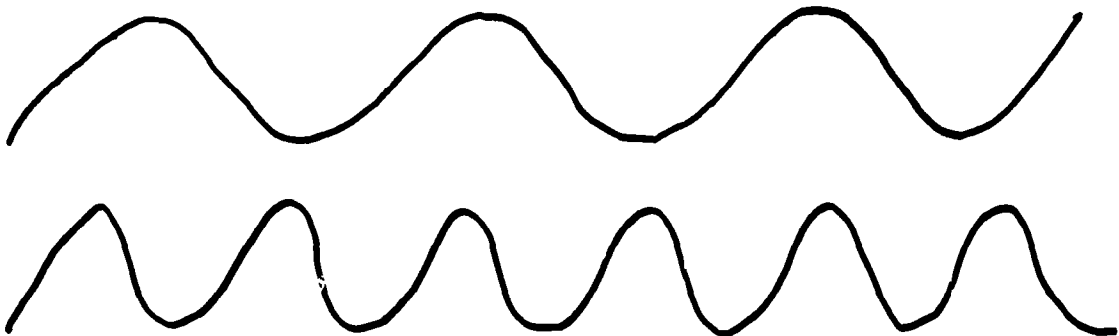
B-747
CRUISE

MAX
NTF

0 20 40 60 80 100 120 × 10^6

$R_{\bar{c}}$

- What Is Admissible Height ?

  — Maximum Peak to Mean Line
  — RMS Height

- Is Admissible Height a Function of Peak Density ?

Top of Laminar Sublayer

rms Roughness

Mean Line

Surface Profile
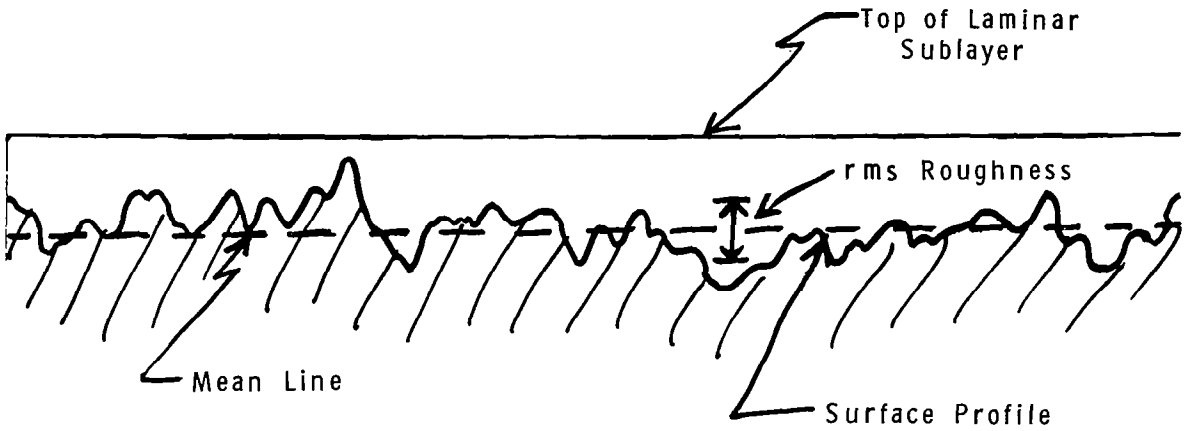
PARAMETER NEEDS

- Height Measure
- Wavelength Measure

Same rms