A housing block is provided having an upper surface conforming to the test surface of a model or aircraft. An oil film is supplied upstream of a transparent wedge window located in this upper surface by an oil pump system located external to the housing block. A light source located within the housing block supplies a light beam which passes through this transparent window and is reflected back through the transparent window by the upper surface of the oil film to a photo-sensitive position sensor located within the housing. This position sensor allows the slope history of the oil film caused by an aerodynamic flow to be determined. The skin friction is determined from this slope history. Internally located mirrors augment and sensitize the reflected beam as necessary before reaching the position sensor. In addition, a filter may be provided before this sensor to filter the beam.

18 claims, 2 drawing sheets
REFLECTION TYPE SKIN FRICTION METER

ORIGIN OF THE INVENTION

The invention described herein was made jointly in the performance of work under a NASA Contract and an employee of the United States Government. In accordance with 35 U.S.C. 202, the contractor elected not to retain title.

BACKGROUND OF THE INVENTION

1. Technical Field of the Invention

The present invention relates generally to skin friction meters and more particularly to a reflection type skin friction meter for both flight and wind tunnel applications.

2. Discussion of the Related Art

The determination of skin friction is very important in fluid mechanical studies or aerodynamic effects. Several methods have been disclosed and include a dual beam interferometer disclosed in U.S. Pat. No. 4,377,343 to Monson. In this patent, each beam is read by a light detector to measure the thickness of an applied oil film at two different points in order to generate a thickness history indication of skin friction by counting the number of interference fringes. A clean, particle free flow is required since the presence of, e.g., a dust speck in the oil film can disrupt the required continuous counting. Also, this method is very sensitive to vibration, requires a relatively large laser capable of producing coherent light in order to obtain good interference fringes, is not easily adaptable from wind tunnel test to flight conditions, requires an optically smooth surface for the interferometer, and has a complicated optical system to produce the necessary two beams.

Another proposal for measuring skin friction is disclosed in U.S. Pat. No. 3,714,824 to Bush. A ring shaped element is placed in a seat in an upright container and subjected to an air flow. The frictional forces of the flow will overcome gravity and lift the ring off its seat at a point corresponding to the specific skin friction. This method only permits the determination of large threes, namely skin friction, gravity and pressure forces, namely skin friction, gravity and pressure gradient. For a film having a small thickness compared to its length and width, the latter two forces are small. In addition, surface tension is negligible except at the leading edge of the oil film. The wall-shear stress at the airforce interface $\tau_w$ is defined as

$$\tau_w = \frac{\rho V^2}{2h}$$

where $t$ is time, $\theta$ is the oil film slope at time $t$, and $\mu$ is the oil viscosity. When the oil film is thin, i.e., is measured in nanometers, it sticks to the surface in most situations so that the fluid surface has negligible velocities compared to the air located a very short distance above. Accordingly, the determined $\tau_w$ at the air-oil interface is equivalent to the wall-shear stress of the boundary layer. Assuming that the oil viscosity is known, this wall stress can be determined by measuring the slope history and using this to determine $\theta$ and $t$ from the best fit to a rectangular hyperbola. This curve is shown in FIG. 2.

Referring to FIGS. 1 and 3, an oil film $10$ is applied to an aerodynamic outer solid surface of a model or aircraft $12$ which is subjected to an aerodynamic flow such as air or other gases. An internal housing block $13$ is provided within the model or aircraft and has an upper
surface 13a conforming with surface of the model or 
aircraft 12. Oil of known viscosity μ is supplied to hous-
ing upper surface 13b by an on-demand external pump 
14 from external reservoir 16, through conduit 18, and 
to spanwise slot or port 20 in housing upper surface 13c. 
Port 20 is located upstream, e.g., one cm upstream, of 
the location where the skin friction stress τw is to be 
measured. Oil supply component 18 is located within 
housing 13. Pump 14 and reservoir 16 are usually sepa-
rate and external to housing 13.

The internal reflection type oil film skin friction 
RB1 is also located within housing 13. A light source 
22 such as a solid state diode laser or small filament 
tungsten light with focusing lens is provided to supply a 
light beam 24 through an inner side of a transparent 
window 26 fitted into an aperture in aerody-
namic surface 13a such that the oil film is located above 
the window having an outer side located flush with the 
surface. Since the light beam need not be coherent, a 
diode laser or small filament tungsten light with focus-
ing lens may be used rather than a larger, coherent light 
producing laser. Transparent wedge window 26 may be 
composed of any suitable transparent material such as 
transparent plastic. The window 26 may also have a 
relatively small, circular shape of, e.g., 10 mm in diam-
eter. A wedge window is used to avoid multiple reflec-
tions. Light beam 24 passes through transparent win-
dow 26 and is reflected internally by the upper or outer 
surface of oil film 10 at an oil film aerodynamic flow 
interface and returned via transparent window 26 to a 
photo diode position sensor 28. This sensor determines 
the location of the center of the intensity of the beam of 
light reaching it. As the slope of oil film 10 changes with 
time, the location of the returned beam 24 on position 
sensor 28 also changes. The output voltage of position 
sensor 28 is processed and stored in an external and 
separate electronic circuit 29 connected by wiring 29a, 
for subsequent processing and display of the skin fric-
tion value τw computed by known methods from 
τw=μ/θt, where μ is the viscosity and θt is the slope 
history. A cascade of reflecting mirrors 30a, 30b, 30c 
and 30d may be employed to augment the length of the 
returned light beam 24 and to improve the sensitivity of 
the sensor beam location. For example, the total re-
lected length of beam 24 may be approximately six and 
one-half inches. An optical filter 32 may also be em-
ployed to filter the beam before it reaches position sen-
or 28 in order to reduce the effect of or block stray 
light.

The provision of light source, mirrors and position 
sensor within housing block 13 allows these optical 
components to be rigidly mounted therein in a prea-
ligned aligned manner prior to rigid installation of the 
housing block within the model or aircraft. Ac-
Accordingly, relative vibration between the optical com-
ponents and the test model or aircraft outer surface can 
be avoided or eliminated. The entire housing is ex-
tremely compact and may fit within a palm. For example, 
a constructed embodiment of the housing has the fol-
lowing dimensions: 1.5×1.5×1.5 inches, excluding the 
diode laser or compact tungsten lamp, and the oil reser-
voir, the pump, and output electronics.

The present invention is also relatively insensitive to 
particles or other contaminants in the oil originating 
from the airflow or oil itself, since the oil film slope 
history is smoothed for high frequency noise and low 
frequency local deviations from the mean rectangular 
hyperbola, and thus the smoothed curve can still give 
the correct skin friction even if part of the raw history 
is contaminated by dust in the oil. This provokes an 
advantage over interferometry which cannot give useful 
results when the continuity of any part of the time 
record is broken. Also, the present invention may be 
used to test a wide variety of surfaces which are hydro-
dynamically smooth but not necessarily optically 
smooth and which are exposed to airflows of various 
velocities in both test and in-flight environments.

Many modifications, improvements and substitutes 
will be apparent to one skilled in the art without depart-
ing from the spirit and scope of the present invention as 
described and shown in the specification and drawings, 
and as defined in the following claims.

What is claimed as new and desirable to be secured 
by Letters Patent is:

1. An apparatus for measuring the skin friction of an 
aerodynamic surface exposed to an aerodynamic flow, 
the apparatus comprising:
a transparent window having an outer side located 
flush with the aerodynamic surface and an oppo-
sitely located inner side;

2. The skin friction measurements apparatus accord-
ing to claim 1, wherein said light source is a diode laser.

3. The skin friction measurement apparatus according 
to claim 1, wherein said light source is a compact tung-
sten light with focusing lens.

4. The skin friction measurement apparatus according 
to claim 1, wherein said means for detecting the position 
of the reflected beam comprises a photo diode position 
sensor.

5. The skin friction measurement apparatus according 
to claim 1, further comprising reflecting mirrors ar-
ranged to reflect the reflected light beam prior to said 
means for detecting the position of the reflected beam, 
wherein the length of the beam is augmented.

6. The skin friction measurement apparatus according 
to claim 3, further comprising an optical filter for filter-
ing the light beam before the beam reaches the photodi-
ode position sensor to reduce the effect of stray light.

7. The skin friction measurement apparatus according 
to claim 1, wherein said transparent window is wedge 
shaped to prevent multiple reflections of the beam.

8. An apparatus for measuring the skin fric-
tion of an aerodynamic outer surface of a structure 
exposed to an aerodynamic flow, said apparatus com-
prising:
a transparent window having an outer side located 
flush with the aerodynamic surface and an oppo-
sitely located inner side;

9. The skin friction measurement apparatus accord-
ing to claim 1, wherein said transparent window is wedge 
shaped to prevent multiple reflections of the beam.

10. The skin friction measurement apparatus accord-
ing to claim 1, wherein said transparent window is wedge 
shaped to prevent multiple reflections of the beam.
The internal skin friction measurement apparatus according to claim 8, where the transparent window is located in an upper surface of said housing.

A method for determining the skin friction on an aerodynamic surface subjected to an aerodynamic flow, the method comprising the steps of:

- providing a transparent window having an outer side flush with the aerodynamic surface and an oppositely located inner side;
- applying oil of known viscosity to the surface upstream of the transparent window, whereby an oil film having a sloped outer surface is formed on the outer side of the transparent window by the aerodynamic flow;
- directing a light beam through the inner side of said transparent window and into the sloped oil film, whereby the light beam is reflected by the sloped outer surface of the oil film at an oil film-aerodynamic flow interface back through the oil film and the transparent window;
- detecting the position of the reflected light over a period of time;
- determining a slope of the oil film based on the detected position of reflected light; and
- determining the skin friction \( \tau_w \) of the aerodynamic surface from the following relationship:

\[
\tau_w = \mu / (\theta t),
\]

wherein \( \mu \) is the known viscosity of the applied oil, \( \theta \) is slope of the oil film determined from the detected position of the reflected light, and \( t \) is the time of detection of the reflected light beam.

The method according to claim 16, further comprising optically filtering the reflected beam prior to said position detecting step to block stray light.

The method according to claim 16, further comprising augmenting the length of the reflected beam prior to said position detecting step.