TRI-SERVICE CORROSION CONFERENCE 2007
ARMY • NAVY • AIR FORCE • MARINES • COAST GUARD • NASA

COEFFICIENT OF FRICTION, THE DEVELOPMENT OF A STANDARD PORTABLE DEVICE FOR THE US NAVAL FLEET

Darren Melhuish PE and John Wegand
Science and Engineering Technologies, Inc.
6551 Loisdale Court, Suite 601
Springfield, Virginia 22150

ABSTRACT

Operational and maintenance requirements have required improved decking systems, particularly non-skid, to be incorporated within the US Navy. For those who have experienced rough seas and foul weather, the importance of good non-skid (or slip resistant) deck coverings on weather decks becomes very apparent. But what defines “good” may be easier to qualify rather than quantify. This is directly related to the methodologies employed to evaluate slip resistance of these surfaces and other deck systems.

INTRODUCTION

Numerous devices exist to measure the coefficient of friction (COF) for flooring, roads, runways, and deck surfaces. As non-skid systems have evolved, the device to evaluate the frictional characteristics within the technical specifications changed to meet testing requirements within the Navy.

The proceeding addresses the problems encountered leading to the development of a compact, portable fieldable COF testing system. The parameters/procedures, used to evaluate non-skid deck coatings to verify their suitability for service or their need for replacement, are also reviewed; this review is not limited to the safety impacts of COF but also the operational readiness impacts on the Fleet.

HISTORY OF NON-SKID DECK COVERINGS

In order to appreciate the development of COF machines for non-skid, it is valuable to understand the evolution of the non-skid. From available documentation, current and past, the chronological path of non-skid implementation and development within the Navy can be mapped from the first use of non-skid materials to the current technologies used today.

The earliest coatings were first called non-slip, and they were simply cast aggregate (sand) into wet paint. The aggregate that did not adhere after the paint dried was simply swept away. Durability of this type of system was questionable, especially under aircraft and heavy equipment traffic which prompted the Navy to develop a technical standard.[1]

The first military specification for non-slip deck coverings was MIL-D-23003, Type I & II (12 September 1961). Type I coatings were single component paints with aggregate mixed in. Developed by industry, they were mostly applied by trowel, or notched trowel. However, they could also be brushed, rolled or sprayed, and had a manageable pot-life of 6-8 hours.[2] Since they did not have a curing agent component, they could be sealed for additional applications if used within 4-6 hours of opening.

Type I was not as wear resistant as Type II. Type II was a two component non-slip, aggregate deck covering. It had a significantly shorter pot-life than the single component predecessors. While a 1-2 hour pot-life required some technical changes to the way it was applied, it was not a real problem for experienced applicators.[3]

In 1964, BUSHIPS Notice 9190 (25 February 1964) directed that MIL-D-23003, Type I deck coverings be discontinued on Aircraft Carriers, Submarines and other service areas. In carrier landing areas, Type I was to be replaced by either a non-abrasive MLC-1157A (two part epoxy resin) or non-abrasive MLC-1169A (two part moisture cure polyurethane resin) to reduce wear of arresting cables. In all non-landing areas, Type I was replaced with MIL-D-23003, Type II deck coatings due to coating wear/durability issues.[4]

Both the MLC-1157A and MLC-1169A were developed to reduce the abrasiveness of non-slip deck coverings in the arresting cable areas of carriers. Many materials were evaluated. Eventually, mineral grit was replaced by both beads and angular glass in these two non-abrasive formulations.[5]

In 1968, a repair material, designated NASL-C-1350, was used to repair damaged or worn areas on MLC-1169A. It was a quick curing, non-cable wearing (angular glass), single-component moisture-cure polyurethane that was trowel applied. One characteristic of this material was that it was ready for traffic after 5 hours of cure (~60^{o}F); this was an important feature of a repair compound for in-service flight decks. Its properties were compared with other Type II, MIL-D-23003 materials. It was found to be suitable for use over worn epoxy-based, non-slip coatings and worn MLC-1169A deck coverings.[6]

In 1969, due to increased air operations, the durability of the MLC-1169A and other commercially available glass bearing coatings became an issue as they needed more frequent repair. The Navy evaluated a new commercially available non-abrasive, non-slip. This commercially available non-slip contained aluminum particles instead of glass.

This aluminum filled particle material was tested and evaluated to have similar COF values to MLC-1169A in both new and worn states. But it was slightly less abrasive on the arresting gear cables, and it was significantly more wear resistant than the MLC-1169A formulation. As a result, this commercially available aluminum filled particle non-slip soon replaced MLC-1169A on metal decks in landing areas. However, MLC-1169A with its glass grit was still used on landing areas of wooden deck carriers. The success of aluminum particles in landing areas is still seen in today's non-skid.[7]

A move in the coating industry, from towel applied methods to spray, were incorporated within a new specification standard. MIL-D-24483 was released on 8 May 1973 and updated on 19 August 1974 as MIL-A-24483A. MIL-D-24483A had a dramatic life; it was canceled by official notice on 11 September 1986, reinstated on 17 April 1989 only to be cancelled again on 31 March 1997. During its tenure, this specification addressed spray-applied, non-slip deck coverings. It consisted of two types:

Type I	General Purpose
Type II	Aircraft carrier landing areas

These non-slip deck coverings were designated a two coat system with the primer conforming to MIL-P-24441/1 (F-150) and the topcoat, a two part synthetic resin compound consisting of a base resin with aggregate and a hardener. Type II was required to have cable abrasion resistant properties. Requirements for dry, wet and oily values for coefficient of friction were designated (Table 1).

On 25 February 1980, MIL-D-23003 was superseded by MIL-D-23003A (Revision A). In this revision there were three classification types:

Type III	General Purpose
Type IV	Aircraft carrier landing and run-out area (non-abrasive to steel arresting cable)
Type V	General Purpose interior or exterior

Revision A specifically addressed application by roller only (smooth, hard core), as well as a description of the peak texture of the rolled non-slip.

The Revision A non-slip was described as a system designating conformance to MIL-P-24441/1 (F-150) for the primer and topcoat consisting of a two part synthetic resin compound (base resin with aggregate and hardener). Requirements for dry, wet and oily values for coefficient of friction were also designated (Table 1). MIL-D-23003A was amended on 10 January 1983, inactivated on 22 April 1998, and finally cancelled on 13 April 1999 ending nearly a forty-year life of this military specification.

Finally, the Navy issued DOD-C-24667 on 11 September 1986; it superseded both MIL-D-23003A and MIL-D-24483A. DOD-C-24667 initially combined the spayed and rolled non-skid into one specification. It is also important to note that this was the first document referencing these deck coverings as non-skid instead of non-slip. Amendments soon followed the initial release of DOD-C-24667.

DOD-C-24667 Amendment I was issued on 30 October 1986, and Amendment II was issued on 9 February 1987. In the first set of iterations, there were three basic types:

Type I (A/B)	General Purpose deck coating
Type II (A/B)	General Purpose interior or exterior deck coating
Type III (A/B)	General Purpose resilient deck coating (for use on wooden decks or where more flexibility is required and where increased weight is not a factor)

Each type had a further designator for High (A) or Low (B) volatile organic content. Also each type had a choice of either:

Composition G- General use abrasive deck coating
Composition L- Limited use aircraft carrier landing and run-out deck coating, except for Type III

The final designator for these three types were:

Grade A	High durability
Grade B	Standard durability

Class 1 – Application by roller trowel
Class 2 – Application by spray, except for Type III

DOD-C-24667 specification also references the non-skid system as a multi-coat deck covering. Both the primer and the non-skid were to have organic binders and pigments. The non-skid was to also have aggregate incorporated. Coatings in this system could be either one or two part materials. Requirements for dry, wet and oily values for coefficient of friction were also designated for Grades A and B for initial and worn states.

Eventually the Military Specification for non-skid was replaced by a Performance Specification MIL-PRF-24667A, issued on 14 August 1992. While the COF value requirements and criteria for the coating system stayed the same, the most notable change was the simplification of the classification of non-skid types:

Type I	High durability, rollable deck coating
Type II	Standard durability, rollable or trowel deck coating
Type III	Standard durability, rollable resilient deck coating (for use on exterior wooden decks or where flexibility is required and where increased weight is not a factor)
Type IV	Standard durability, sprayable deck coating

Most types had a choice of either:

Composition G	General use abrasive deck coating (Types I, II, III, and IV)
Composition L	Limited use aircraft carrier landing and run-out area deck coating which is not abrasive to the steel arresting cable (Types I & II only)

At this present time, the most current Naval non-skid reference is MIL-PRF-24667B, issued on 3 June 2005. The major difference between the current version and its predecessor is the increased variety of non-skid Types:

Type I	High durability, rollable deck coating
Type II	Standard durability, rollable or trowel deck coating
Type III	Standard durability, rollable resilient deck coating (for use where flexibility is required and where increased weight is not a factor)
Type IV	Standard durability, sprayable deck coating
Type V	Extended durability, rollable deck coating
Type VI	High durability, fast cure, rollable deck coating
Type VII	Fast cure, temporary repair, rollable deck coating
Type VIII	Low temperature cure, rollable deck coating

Type IX	High temperature resistance deck coating
Type X	Submerged applications

Most types have a choice of either:

Composition G	General use abrasive deck coating (all Types)
Composition L	Limited use aircraft carrier landing and run-out area deck coating that is not abrasive to the steel arresting cable (Types I, V, VI, VII, VIII & IX only)

HISTORY OF COF NON-SKID TESTING

Each non-skid specification had its own variation for determining the minimum acceptable values for COF. Before we discuss these various methods used throughout non-skid history, let's first firmly grasp the concept of what the coefficient of friction really is. Consider a block on a flat table (Figure 1). If a force (F) is applied to the block, a frictional force (f) acts in the opposing direction. If F is not larger than f, the block remains stationary. This force acting in the opposite direction is called the force of static friction (f_s). However, if the applied force F is large enough to overcome the force of static friction, the block will start to move. At this point, the static frictional force is at its maximum ($f_{s,max}$). When the block slips, it will accelerate in the direction of the applied force F. Once the block it is in motion, the retarding fictional force is less than $f_{s,max}$ and is called the force of kinetic friction, f_k. Figure 1 graphically depicts the change in frictional state.

If the applied force (F) is removed, the frictional force acting on the block will eventually decelerate the block and cause it to come to rest.[8]

"Experimentally, one finds that both f_s and f_k are proportional to the normal force (weight) acting on the block. Giving us the following laws of friction:

1) The force of static friction between any two surfaces in contact is opposite the applied force and can have values given by

$$f_s \leq \mu_s N \quad \text{where} \quad f_{s,max} = \mu_s N \qquad \text{Equation (1)}$$

Where N is defined as the normal force and μ_s is a dimensionless constant called the coefficient of static friction.

2) The force of kinetic friction acting on an object is opposite to the direction of motion of the object and is given by

$$f_k = \mu_k N \qquad \text{Equation (2)}$$

Where N is defined as the normal force and μ_k is a dimensionless constant called the coefficient of kinetic friction."[9]

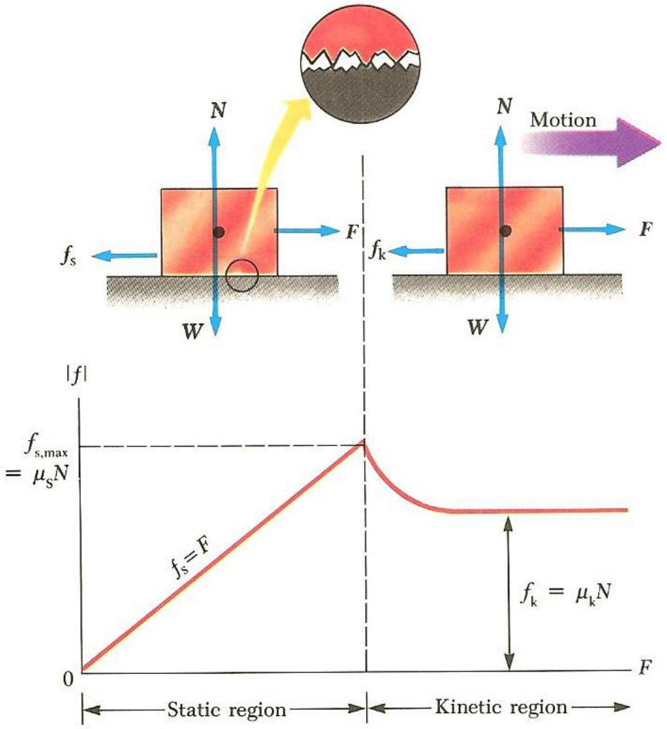

Figure 1: Definition of Frictional Forces[10]

By definition the coefficient of friction "is an intrinsic property of the two interfacing, interaction surfaces and serves as a measure of their micro and macro roughness, inter and intra molecular forces of attraction and repulsion and their viscoelastic (polymer deformation) properties. As such, the area of contact, duration of contact before movement, velocity of movement, pressure, etc are contributing factors to the coefficient of friction results obtained and also to the inconsistency of the values observed when different friction testers, sensors and/or protocols are employed."[11] This means is that the coefficient of friction is a measurable constant dependant on the nature of the two surfaces in contact with each other. For example the COF constant for rubber and non-skid is different from leather and non-skid.

Typically μ_s is greater than $\mu_{k,}$ as it takes more force to break an object loose that it does to keep it moving. Because the Navy is most concerned with the prevention of slipping/skidding, this paper is primarily referring to static coefficients of friction, whenever COF is discussed.

Now we know the definition of COF, but how is it measured? The most primitive method for determining the value of COF is to imagine a block on an inclined plane (Figure 2). Based on the inclined plane, we can derive the static coefficient of friction from basic force balances.

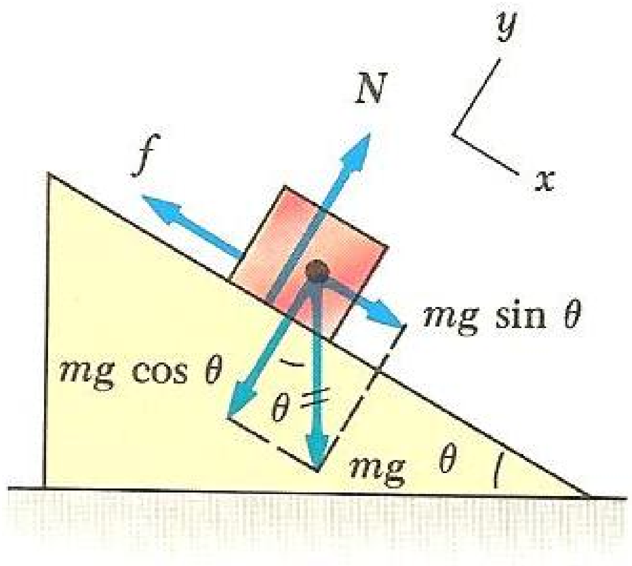

Figure 2: Block on Inclined Plane[12]

First, let us start with the definition of static friction. A static frictional force is a force that keeps the block from moving. From the laws of friction listed above, we know that $f_{s,max}=\mu_s N$. In this case the block will not move until the force of gravity exceeds the force of friction. Hence, we can increase the force of gravity by increasing the angle (θ) of the inclined plane; all other things kept constant, θ will be our variable.

Second we perform force balances with respect to our orientated x-y plane:

$\Sigma F_x = (mg)(\sin\theta) - f_s = 0$ or $(mg)(\sin\theta) = f_s$ Equation (3)
$\Sigma F_y = N - (mg)(\cos\theta) = 0$ Equation (4)

Rearrangement of Equation (4) leads to:

$mg = N/(\cos\theta)$ Equation (5)

Substitution of Equation (5) into Equation (3) leads to:

$$\frac{N}{\cos\theta} \times \sin\theta = f_s \qquad \text{Equation (6)}$$

By definition $\tan\theta = \sin\theta / \cos\theta$, therefore Equation (6) becomes:

$(N)(\tan\theta) = f_s$ Equation (7)

From the laws of static friction when θ is increased and the block starts to move we have reached the maximum force of friction and therefore:

$f_{s,max}=\mu_s N$ Equation (1)

Substitution of Equation (1) into Equation (7) yields:

$$(N)(\tan\theta) = \mu_s N \text{ or simply } \mathbf{\tan\theta = \mu_s} \qquad \text{Equation (8)}$$

This tells us that the tangent of the angle the instant the block begins to move equals the static coefficient of friction. This is the theory of the James Machine (Figure 3) described in ASTM D2047.

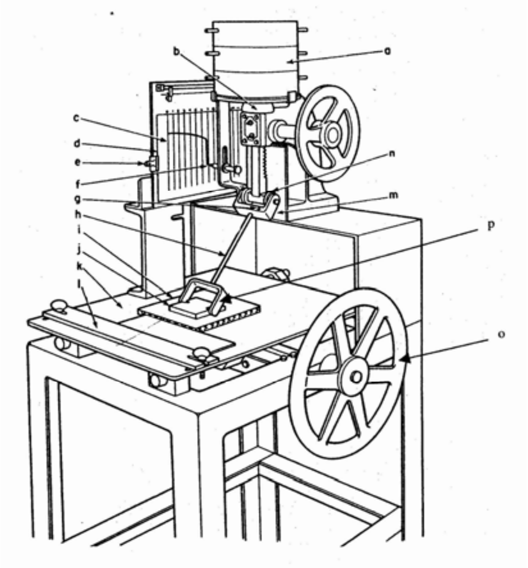

Figure 3: Diagram of the James Machine[13]

The James Machine was developed in 1944 by Sidney V. James of Underwriters Laboratory Inc. to evaluate floor finishes. It was a device that could determine the coefficient of friction by securing a coupon of flooring material that could incline while a sled with leather, as the contact material, was placed on top of the test coupon. As the incline of the platform with the coupon was increased, a strut attached to the sled was recording the value of the angle. The angle at which the sled moved was recorded on the chart denoting the static coefficient of friction.

When the coefficient of friction data first appeared in MIL-D-23003 (12 September 1961), an alternative method for determining friction was used. The first apparatus was a spring scale fixed to a 33-pound sled. The test was performed with both leather and rubber materials acting as the contact surface to the non-skid coating. It was also performed on dry, wet and oily conditions to determine respective COF values, Table 1 contains a summary of COF values for these various conditions. The amount of force required to break the sled from its fixed position was recorded as the force of static friction; the amount of force required to keep the sled moving was recorded as the sliding force of friction.

When the static force and sliding force values are divided by the weight of the sled, the static coefficient of friction and the sliding (or kinetic) coefficient of friction are respectively calculated. This approach for measuring static and kinetic frictions lead to variations in COF values, most likely due to the inherent difficultly in accurately recording the force values.

A later attempt to achieve repeatable values was used to mount the test leather or rubber to a portable (belt) sander, let it run along the non-skid coating and have the operator anchor the spring scale. It was assumed that this approach would be more repeatable than with the human providing all the motive power. As far as it is known, this attempt was not used, nor placed in any specifications."[14]

A similar version of the belt sander approach was for laboratory testing of coupon samples. This device was called the NASL Friction Test Apparatus. It was a fixed testing device consisting of a motor driven belt either leather or rubber. A coupon of test material (non-slip) was attached to the bottom of the sled. The sled was attached to a load cell and placed on top of the belt. The belt moved at a constant rate, and a constant normal force was applied to the sled. Friction data was collected from the load cell. This device was also fitted with injection tubes for performing the test in both wet and oily conditions as well.

The NASL Friction Test Apparatus did not produce COF values that correlated to the values specified in MIL-D-23003. The COF data derived from this apparatus did not appear in MIL-D-23003A, but is listed in Table 1 for comparison purposes. Note that other devices mentioned during interviews, but with no details given, included the Lakehurst Rotating Slip Meter and the NATO Slip Meter.[15]

What was needed was a reliable, portable apparatus that could be used in the field to evaluate the deck coverings. In October 1968, a report, titled "Report on Development of an Economical Maintenance Device for Quick Efficient Field Evaluation of Deck Coating Friction," was released. It stated the need for quantitative analysis of existing deck coverings to justify repair or replacement rather than the judgment of deck personnel. A commercially available slip meter made by Olson Medical Products was currently being used by the insurance industry for measuring the slipperiness of floors. When the feet of the Olson Slipmeter sled are fitted with neoprene rubber, it was found to effectively measure the coefficient of friction.

The Olson tester was small, compact and simple to operate. However, this report recommended that the use of this slipmeter be postponed for the purposes of evaluating deck coatings onboard ships until safe limits for COF were established in field tests.[16]

When MIL-D-23003A was issued on 25 February 1980, the apparatus specified for evaluating the COF of non-slip deck coverings was the Olson Slipmeter, modified with vulcanized, neoprene rubber feet with a Shore A hardness of 85 +/- 5 durometer. This apparatus consisted of two main components: 1) a motor driven pulley, and 2) a sled apparatus consisting of a force gauge and three feet as the contact points. A cable from the motor was attached to a hook on the force gauge of the sled. When activated the motor would pull the sled at a constant rate of 4 inches per minute, the force gauge would register the frictional force. The maximum frictional force recorded prior to the block moving was divided by the weight of the sled (~6 pounds) to yield the resulting static coefficient of friction. In previous standards both the static and kinetic coefficients of friction were listed, but, starting with MIL-D-23003A, only static COF was listed as this was considered the critical one in terms of prevention of slips/skids.

Two sets of rubber feet were designated for this test, one was for the dry and wet (synthetic seawater, ASTM D1141) test, the second set was for the oily (SAE 10W) surface condition test. COF values for MIL-D-23003A are included in Table 1.

Spray applied non-slip deck coverings had their own COF values and procedure as called out in MIL-D-24483A (19 August 1973). This procedure was almost identical to the one previously mentioned in MIL-D-23003D. It too used a modified Olson Slipmeter, however the specification specifically called for vulcanized neoprene rubber having a Shore A hardness range of 60-80 durometer. This appears to be the only difference in the apparatus between MIL-D-23003A and MIL-D-24483A; COF values for MIL-D-24483A can be found in Table 1.

When the DOD-C-24667 non-skid standard came out on 11 September 1986, a new device for measuring COF was specified, the NAVSSES Slipmeter (Figure 4). This apparatus consisted of a steel sled (6.0 +/- 0.5 pounds) fitted with a 1/8" thick, vulcanized neoprene rubber with a Shore A hardness of 65 +/- 5 durometer. The sled could be hooked onto an electronic digital force gauge capable of retaining the highest force encountered, with a sensitivity of measuring forces within one hundredth of a pound. The force gauge was attached to a mechanical screw driven slide that would move at a rate of 10 +/- 2 inches per minute, and travel a distance of 4 inches. The highest force recorded by the gauge was used to compute the COF by dividing it by the weight of the sled.

This specification also called out requirements for dry, wet and oily tests as well as their respective minimum values. Instead of SAE 10W oil as referenced in previous specifications, aircraft turboshaft engine oil (MIL-L-23699) was specified. Minimum COF values required for DOD-C-24667 can be found in Table 1.

The procedure for evaluating COF values changed very little in the updated version A of the non-skid MIL-PRF-24667A. Most notable was that the vulcanized neoprene hardness was reduced to 57 +/- 2 durometer on the Shore A scale. Also, the speed at which the sled was pulled increased to a nominal 12 inches per minute. Clarification was provided for each test of dry, wet and oily to have its own designated sled to prevent cross contamination. Minimum COF values required for MIL-PRF-24667A are summarized in Table 1.

Figure 4: Portable NAVSSES Slipmeter design circa 1996

The most current performance specification for non-skid (MIL-PRF-24667B), released on 3 June 2005, bears a similar procedure to its predecessor with minor alterations to the NAVSSES Slipmeter. In the original versions the sled was a true block with all right angles for corners. However in this revision the leading edge of the sled in the direction of pull was given a ¾" radius. The radius helped elevate some of the radical non-skid peaks that could cause a square edge to hang resulting in a false high COF value.

Other notable modifications to the NAVSSES Slipmeter were due to technology advancements. The requirement that the force gauge have a minimum resolution of +/- 0.02 pounds and the ability to output information directly to a computer for analysis was specified. Also, this computer must have a program with the ability to receive data from the force gauge as well as analyze that data to determine the static COF at the moment the block moves.

The real-time data recorded provided instantaneous applied forces allowing the true static COF value to be calculated by identification of the sudden change in slope of the force curve, like that shown earlier in Figure 1. All this information could be gathered within a 1 inch pull. As a result of these requirements for stricter data capture, the requirement for moving the sled 4 inches and recording the maximum force measured within this distance was no longer necessary.

Table 1: Historical Friction Requirements for the Non-skid within the U.S. Navy

Reference	Contact Material	Coefficient of Friction (minimum)		
		Dry	Wet	Oily
MIL-D-23003 Type I & II 12 September 1961 33 lb sled pulled with a spring scale	Leather **Static**	0.85	0.85	---
	Rubber **Static**	1.00	1.00	1.20
	Leather **Sliding**	0.50	0.60	---
	Rubber **Sliding**	1.00	1.00	1.00
NASL Friction Test Apparatus, circa 1967	Leather **Static**	0.50	0.60	---
	Rubber **Static**	0.40	0.45	0.25
	Leather **Sliding**	0.35	0.35	----
	Rubber **Sliding**	0.90	0.80	0.30
MIL-D-23003A 25 February 1980 Olson Slipmeter vulcanized neoprene rubber 85 (+/- 5) durometer	Rubber **Static** (Types III & V)	0.90	0.90	0.90 SAE 10W
	Rubber **Static** (Type IV After Cable Wear Test)	1.00	0.95	0.95 SAE 10W
MIL-D-24483A 19 August 1974 Olson Slipmeter vulcanized neoprene rubber 60-80 durometer	Rubber **Static** Initial	1.15	1.00	0.95 SAE 10W
	Rubber **Static** After wear test	1.10	1.00	0.95 SAE 10W
	Rubber **Static** After Cable Wear Test (Type II only)	1.00	0.90	0.50 SAE 10W
DOD-C-24667 11 September 1986 NAVSSES Slipmeter vulcanized neoprene rubber 65 (+/- 5) durometer	Rubber **Static** Grade A initial condition	0.95	0.90	0.80 MIL-L-23699
	Rubber **Static** Grade B initial condition	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Grade A After cable Wear	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Grade B After cable Wear	0.80	0.75	0.65 MIL-L-23699

Reference	Contact Material	Coefficient of Friction (minimum)		
		Dry	Wet	Oily
MIL-PRF-24667A 14 August 1992 NAVSSES Slipmeter vulcanized neoprene rubber 57 (+/- 2) durometer	Rubber **Static** Type I initial condition	0.95	0.90	0.80 MIL-L-23699
	Rubber **Static** Type II, III & IV initial condition	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Type I After cable Wear	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Type II, III & IV After cable Wear	0.80	0.75	0.65 MIL-L-23699
MIL-PRF-24667B 3 June 2005 NAVSSES Slipmeter vulcanized neoprene rubber 57 (+/- 2) durometer Sled with front edge radius Force gauge output to PC Data capture and analysis program	Rubber **Static** Type I, V, VI, VII, VIII & IX initial condition	0.95	0.90	0.80 MIL-L-23699
	Rubber **Static** Type II, III, IV & X initial condition	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Type I, V, VI, VII, VIII & IX After cable Wear	0.90	0.85	0.75 MIL-L-23699
	Rubber **Static** Type II, III, IV & X After cable Wear	0.80	0.75	0.65 MIL-L-23699

When comparing the rubber static and sliding (or kinetic) COF values, MIL-D-23003 required the same value for dry and wet conditions. This is different from what is expected as kinetic COF values are usually less than static. Also, when comparing rubber static and sliding for the NASL Friction Test Apparatus, the sliding COF values are all higher than the static COF values; no explanation was available during the literature review for this paper. It should be noted that the NASL values did not correlate to the values required in MIL-D-23003. Further, note that the values of COF did not change through the various 24667 documents.

It is important to recognize that all these devices were intended to be employed for the evaluation and qualification of non-skid materials on coupons in a laboratory setting to determine if the non-skid met the minimum COF requirements of the specification. Even though some of these machines, particularity the latest two NAVSSES Slipmeters in particular, were used to evaluate non-skid in the field, they were cumbersome at best. They consisted of multiple components that often required at least two operators to effectively use; with the last generation, the motor slide required A/C power.

In order to obtain an accurate overall COF value for a particular location the entire apparatus (motor, sled, PC, power cables, data cables) needed to be orientated in four directions: forward, aft, port and starboard. This took a substantial amount of time to move and setup compared to the actual amount of time to perform the measurements. Thus, there was a need to develop a portable, user-friendly apparatus that was quick and easy to use.

COF TESTER FOR THE FIELD

In order to fulfill this need, Naval Research Laboratories (NRL) investigated various existing devices and methodologies.

The Tortus Floor Friction Tester, used to measure kinetic COF or dynamic COF, was designed to mimic foot-heel loading for the evaluation of floor cleaning materials. However this application was not well suited for non-skid evaluation.

Variable incidence tribometers were also evaluated. One type bio-mechanically mimicked the human gate by utilizing a pressurized piston with a padded foot angled at the contact surface. This unit measured the critical angle of slip when the piston was fired. It was designed to evaluate foot-traffic on relatively smooth surfaces in a unidirectional application, which again would result in multiple measurements for each test location. Further, its application was not well suited for the rough texture of non-skid surfaces.

Another device which showed promise was the Findley Irvine unit. It consisted of a rotating wheel which measured the breaking force required to stop a rotating tire, this force correlates to COF. While this instrument was intended for use in the field, it requires specialized operators and daily calibration. The unit is large and cumbersome leading to some handling problems.

A method for testing COF in the laboratory dating back to 1960 was considered. The technique, known as Ball-on-Flat Method or Pin-on-Disk, has been utilized by the National Center for Tribology in the UK and Centrale Lyon. The concept for the laboratory apparatus version was to place a known contact material on the end of a measurement arm similar to that of a needle on the end of a turntable arm. A test surface coupon was placed on the turntable and rotated to evaluate the surface in a multidirectional fashion.

As the coupon rotates, the arm is placed in contact with the coupon at a fixed load. Strain gauges on the arm directly measures the frictional force applied on the arm during rotation of the coupon.

It was this ball-on-flat method (Figure 5) that was modified for application in the field by fashioning the contact material and strain gauge arm to a mechanism such that it rotated 360° while the test surface was stationary; exactly what was needed for the fleet to evaluate the existing conditions of its non-skid decks.

Figure 5: Early prototype of the portable ball-on-flat COF measuring device.

Multiple prototypes of this NRL designed Ball-on-Flat device were evaluated in order to evolve to the current design (US Patent Number 7,000,451). The design of the portable coefficient of friction meter

(Figure 6) allows for the irregular topography of Naval non-skid and provides 360^{o} COF analysis of the surface eliminating the need to re-orient the unit and retest the same location; this had been the case with previous devices. The current device is user friendly with single button operation, and it provides a Go / No-Go output based on defined performance parameters. The unit is battery powered (AC power backup), compact in size (18” diameter x 7” height) about 10 pounds, and it is capable of on-board data storage for additional review and analysis if desired.

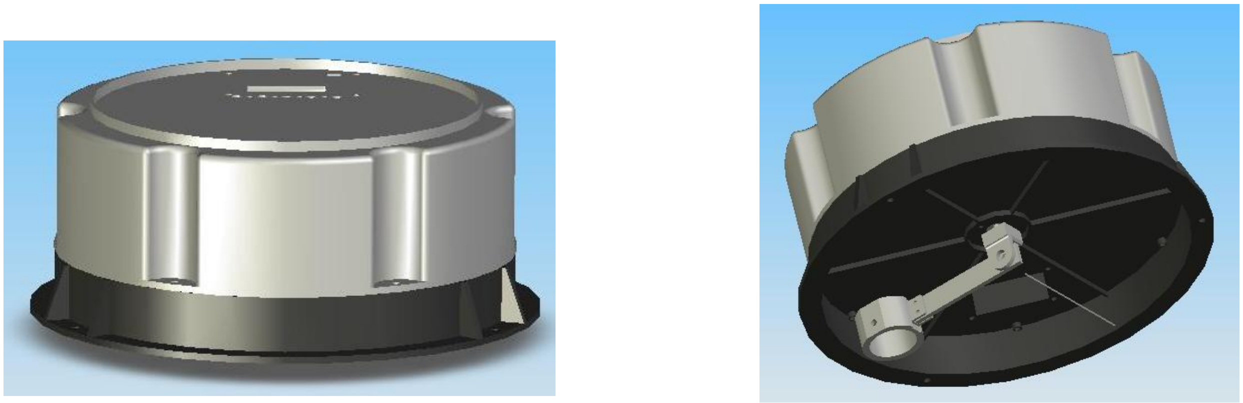

Figure 6: The current version of the portable COF device.

CONCLUSIONS

Not only is the qualification of new non-skid materials important, so is the ability to evaluate existing non-skid on weather decks, particularly flight decks to insure that they meet the requirements deemed necessary for safety. If a flight deck non-skid does not meet the requirements, it has a domino effect on the operational readiness not only of that flight deck but also of the entire battle group.

In general the laboratory apparatus referenced in the specifications and performance standards were not conducive to field testing to verify compliance / noncompliance of in-situ non-skid due to their need for external power sources, multiple components, and multiple test orientations to evaluate one spot. The Navy had a need for a portable, easy to use device which could rapidly identify, via coefficient of friction data, areas of conformance or non-conformance of non-skid decks.

REFERENCES

Griffin, D.L. “A History of Non-Skid Deck Coverings Development.” Contract No. N00167-85-D-0043/0009. Annapolis, Maryland: Native American Consultants, Inc., July 31, 1986.

Sacher, Alex. “Slip Resistance and the James Machine 0.5 Static Coefficient of Friction-Sine Qua Non*,” ASTM Standardization News (August 1993): 52-59.

Serway, Raymond A. Physics for Scientists & Engineers with Modern Physics, Third Edition. Saunders College Publishing, 1990.

ASTM International, ASTM D 2047-04 “Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine” Volume 15.04, July 2004.

MIL-D-23003A “Deck Covering Compound, Non-Slip, Rollable,” 25 February 1980.

MIL-D-24483A “Deck Covering, Spray-On, Non-Slip,” 19 August 1974.

DOD-C-24667 “Coating System, Non-Skid, For Roll or Spray Application (Metric),” 11 September 1986.

MIL-PRF-24667A “Coating System, Non-Skid, For Roll or Spray Application (Metric),” 14 August 1992.

MIL-PRF-24667B “Coating System, Non-Skid, For Roll or Spray Application,” 3 June 2005.

---

[1] Griffin, D.L. “A History of Non-Skid Deck Coverings Development.” Contract No. N00167-85-D-0043/0009. Annapolis, Maryland: Native American Consultants, Inc., July 31, 1986, page 3.

[2] Griffin, D.L., page 3.

[3] Griffin, D.L., page 3.

[4] Griffin, D.L., page 3.

[5] Griffin, D.L., page 4.

[6] Griffin, D.L., page 8.

[7] Griffin, D.L., page 4.

[8] Serway, Raymond A. Physics for Scientists & Engineers with Modern Physics, Third Edition. Saunders College Publishing, 1990, pages 112-113.

[9] Serway, Raymond A. , page 113.

[10] Serway, Raymond A. , page 112.

[11] Sacher, Alex. “Slip Resistance and the James Machine 0.5 Static Coefficient of Friction-Sine Qua Non*,” ASTM Standardization News (August 1993): page 53.

[12] Serway, Raymond A. , page 114.

[13] ASTM International, ASTM D 2047-04 “Standard Test Method for Static Coefficient of Friction of Polish-Coated Flooring Surfaces as Measured by the James Machine” Volume 15.04, July 2004.

[14] Griffin, D.L., page 15.

[15] Griffin, D.L., page 15.

[16] Griffin, D.L., page 15.