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Frictional and retarding forces on aircraft tyres – Introduction to the ESDU methods



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FRictionAL AND RETARDING FORCES ON AIRCRAFT TYRES – INTRODUCTION TO THE ESDU METHODS

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FRictionAL AND RETARDING FORCES ON AIRCRAFT TYRES – INTRODUCTION TO THE ESDU METHODS

1. NOTATION AND UNITS

		Dimension
D	inflated diameter of tyre	L
E^*	dynamic modulus of visco-elastic material	$M L^{-1} T^{-2}$
E'	energy stored in a visco-elastic oscillation	$M L^{-1} T^{-2}$
E''	energy lost in a visco-elastic oscillation	$M L^{-1} T^{-2}$
p_{ABS}	inflated pressure – absolute measure	$M L^{-1} T^{-2}$
t	time	T
V	velocity	$L T^{-1}$
w	tyre width (inflated)	L
X	friction or retarding force	$M L T^{-2}$
Z	normal (to runway) load on tyre	$M L T^{-2}$
δ	phase lag between stress and strain	–
ϵ	strain	–
ϵ_0	strain (maximum value)	–
Λ	tyre loading parameter	–
μ	coefficient of friction or retarding force coefficient	–
ρ	density of visco-elastic solid	$M L^{-3}$
σ	stress	$M L^{-1} T^{-2}$
σ_0	stress (maximum value)	$M L^{-1} T^{-2}$

2. INTRODUCTION

2.1 General

This ESDU Item is a general introduction to the series of Items that address those forces and conditions that originate from the motion of aircraft tyres on paved runways in many states of contamination. Throughout the series every effort is made to ensure that there is a logical progression from simple cases to the more complex. Use is made of data from experiments with rubber blocks in order to identify the effect of the layer of low-strength material that exists between a hard surface and a rubber-based compound in compression. From this small beginning, a coherent model is constructed.

The solutions offered are algebraic: use is made neither of finite-element models of tyres nor of computational fluid-dynamic models of the (multi-phase) flows on the surface of a contaminated runway. Thus, the mathematical models can be used with minimal computational equipment and effort. However, no attempt is made to treat the motion of pneumatic tyres on such unstable surfaces as grass, sand, or gravel.

2.2 Scope of Series

The majority of the topics covered are summarised in ESDU 05011. Detailed derivations are given in:

Data Item	Subject	Details
10015	Rolling Resistance	Dry Water Slush Snow – includes properties of medium
	Tyre characteristics	Rubber properties Tyre mechanical properties
	Braking (dry)	Static Sliding Slipping
	Braking (wet)	Sliding Slipping
	Braking (loose snow)	Sliding Slipping
	Braking (ice and compressed snow)	Sliding Slipping
11004	Multi-wheel undercarriages (wet)	Line astern Line abreast Line astern and abreast
13007	Side-force (dry and wet)	Unbraked only

The hydrodynamic **planing of rib tread aircraft tyres** is covered in ESDU 15003.

Ancillary material is given in:

Publication	Subject
Technical memorandum TM 174	Sharpness of micro-texture
Technical Paper TP 2	Surface porosity from outflow meter
Technical Paper TP 3	Effect of temperature on phase angle
Technical Paper TP 5	Distribution of runway macro-texture in UK
Technical Paper TP 7	Compendium of fitted side-force data
Technical Paper TP 9	Bibliography

3. SOME ASPECTS OF RUBBER TECHNOLOGY

3.1 General

During the Enlightenment of the 17th and 18th centuries, only one kind of friction was recognised. This is what is now described as **mechanical** friction. Because this friction force is *apparently* dependent only on the applied normal load the relationship between load and decelerating force was described as the linear function:

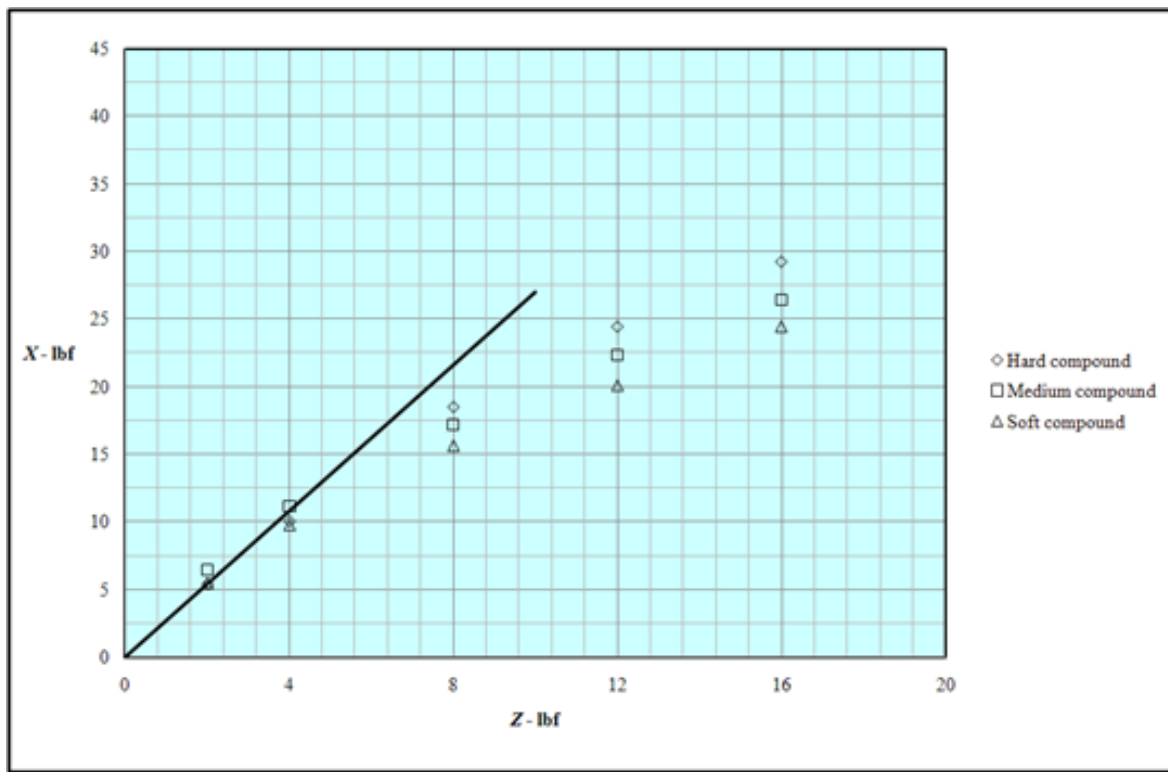
$$X = \mu Z. \quad (3.1)$$

This relationship has been adopted by mechanical engineers as a touchstone of truth ever since it was set down in 1699 by Amontons as his first law of friction. The so-called laws of friction were set out as:

- The force of friction is directly proportional to the applied load. (Amontons' 1st Law)
- The force of friction is independent of the apparent area of contact. (Amontons' 2nd Law)
- Kinetic friction is independent of the sliding velocity. (Coulomb's Law)

It is a sad fact that these three laws apply only approximately even to the case that they were formulated to explain, that is, the mechanical friction between hard solid surfaces. For interactions between other types of materials the laws are not even approximately applicable.

Consider the case shown in Sketch 3.1. These data were collected in an experiment by Schallamach conducted in 1952 using blocks of rubber sliding on plate glass to ***“fill a gap in the understanding of rubber friction”***.



Sketch 3.1 Effect of normal load on decelerating force for various rubber compounds

The speed for all the testing was as close as was possible to zero so that dynamic modes were not excited. Clearly, as load increases, the factor X/Z decreases; this contradicts the first law. Other experiments show that there is a significant relation between normal load, elastic (or Young's) modulus and the area of contact between a rubber hemisphere and a plane, hard surface. This implies that the area of contact increases with load since the rubber is pressed into more intimate contact with the protuberances on the surface. Furthermore, there exists a substantial body of data that shows that decelerating forces, generated between rubber tyres and flat runways of varying roughness, decrease with increasing speed. So, for rubber, which is a visco-elastic material, none of the three laws apply when in contact with hard surfaces.

3.2 Visco-elastic Materials

Visco-elastic materials are those for which the relationship between stress and strain varies with time. Consider a rubber tyre moving under load over a solid surface. At the front of the moving tyre footprint, the rubber is compressed, whilst at the back of the footprint, the rubber relaxes to its unconstrained condition. This process is the source of the losses that constitute resistance to motion. In these circumstances, bonds form at molecular level between the rubber and the material of the surface. Forming and breaking these bonds dissipates energy mostly in the form of heat. This dissipation is manifest as resistance to motion. In the case of a braked tyre the resistance to motion is termed "**friction**". In the case of an unbraked tyre it is more usual to refer to the phenomenon as **rolling resistance**. If only it were not customary to refer to any of these forces as "**friction**", a source of considerable confusion would be eliminated.

Some definitions of terms used in the study of materials are now given.