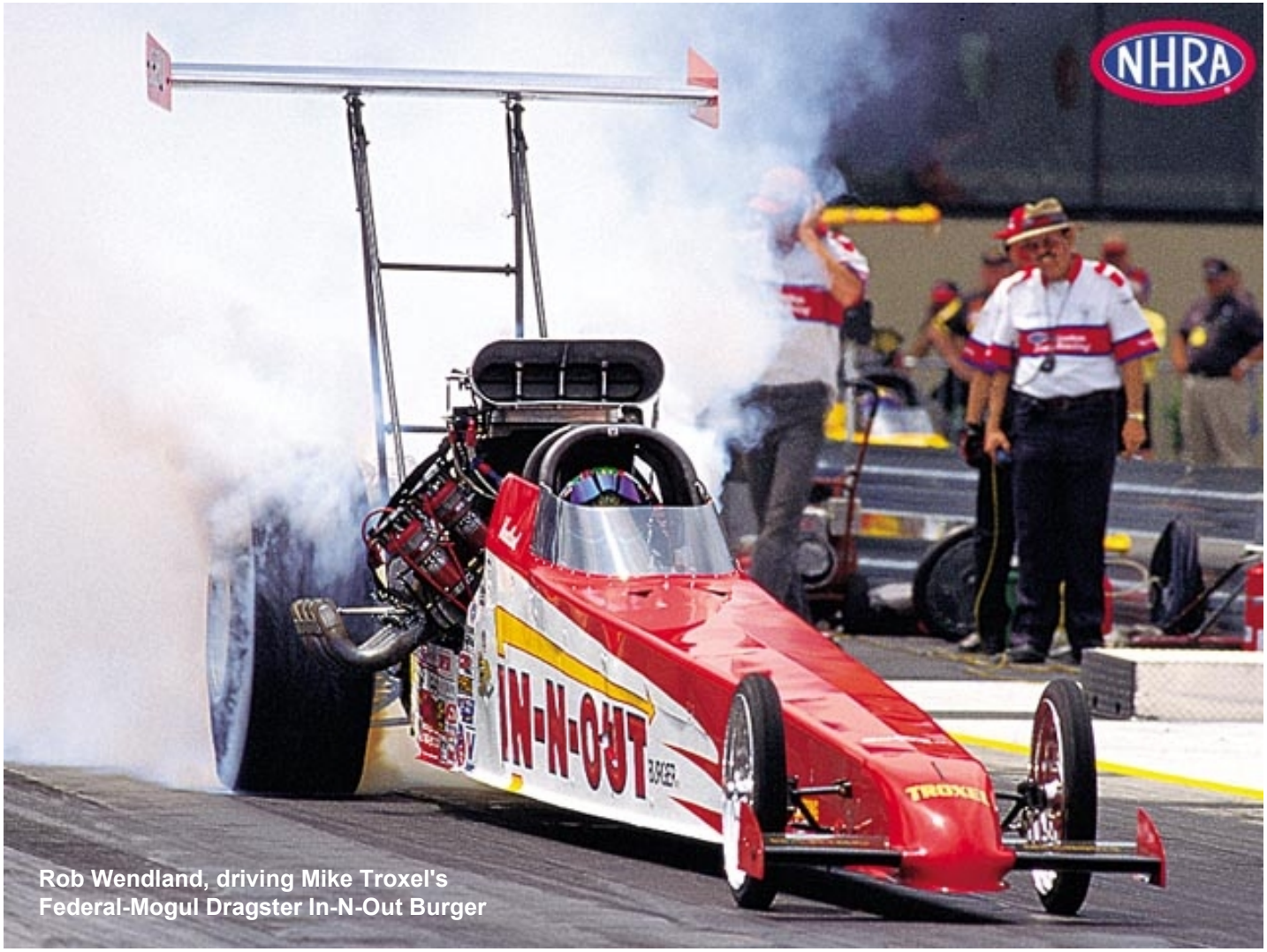
THE NATURE OF FRICTION



Rob Wendland, driving Mike Troxel's Federal-Mogul Dragster In-N-Out Burger

Laws of Friction

- Since friction is such a natural part of day-to-day life, most people do not give it any real thought. However, friction is actually a very complex phenomena. In fact:

> *"It is one of the dirty little secrets of physics," writes David Kessler of Bar-Ilan University today in Nature, "that while we physicists can tell you a lot about quarks, quasars and other exotica, there is still no universally accepted explanation of the basic laws of friction."*

- As one might imagine, this leads to many myths and misconceptions about what friction is, especially among layman. Take some time now to search the Internet for discussion board postings and other non-scientific writings and explanations of the phenomena. Then return here for a brief discussion of the commonly accepted laws of friction and the theories explaning these laws

Laws of Friction

- The laws of friction were developed centuries ago. Even though the theories defining friction are not fully understood, the following laws have been empirically validated
  - For clean, dry surfaces:
    - friction is directly proportional to load (Amonton's 1st law)
    - friction is independent of area (Amonton's 2nd law)
    - at low velocities, friction is independent of velocity. At higher velocities the coefficent of friction decreases. (Coulombs law)
  - For clean, well lubricated surfaces:
    - frictional is nearly independent of load
    - at low pressures, friction varies directly with relative surface speed
    - at high pressures, friction is high at low velocities and falls as velocity increases to some point, then rises proportional to velocity
    - friction is not dependent of the surface materials
    - friction is related to temperature

Laws of Friction

- Take special note of Amonton's second law. Although this law was first published in 1699 as part of Amonton's paper on friction, it is the most difficult law for the layman to grasp and understand. In fact, many people reject this law outright

- In actuality, it is easily proven with a simple experiment. Take a brick, lay it on a table with its large area down, and apply a force until it just begins to move. Now place the brick on edge and repeat the experiment. You will find it took the same force to move the brick thus providing limited empirical evidence of Amonton's first two laws

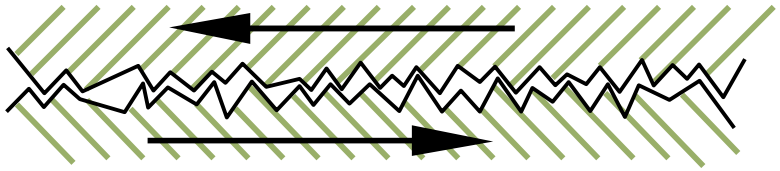
- But if this is true, why do racers, for example, use wide tires on their cars? This question will be answered, but let's first look at some theories of friction to explain these laws

Theories of Friction

- There are several theories of friction of which we should be aware. These are:
  - Interlocking theory
  - Electrostatic theory
  - Chemical bonding theory
  - Adhesion theory
  - Self-Healing Crack theory
- Some of these theories are well established and well understood; others are relatively new theories requiring additional research. At this time, no single theory adequately describes friction

Interlocking Theory

- The interlocking theory of friction is based upon the fact no surface is perfectly smooth. At the microscopic level, even polished surfaces look like the Rocky mountains. This theory states that these ridges, or asperities, interlock to generate a mechanical force we call friction



Micrscopic Asperities Interlock to Generate Frictional Force

- At one time, scientists thought surface roughness was the sole cause of friction. However, it has been shown it only accounts for about 5% of the overall friction coefficient. That is, the friction coefficient remains fairly constant for a 'normal' range of surface roughness

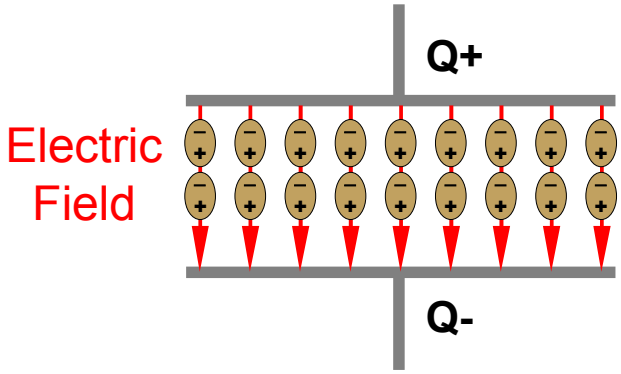
Electrostatic Theory

- The electrostatic theory of friction applies to dissimilar materials. It is based upon an idea that friction is a result of the attraction of charged particles

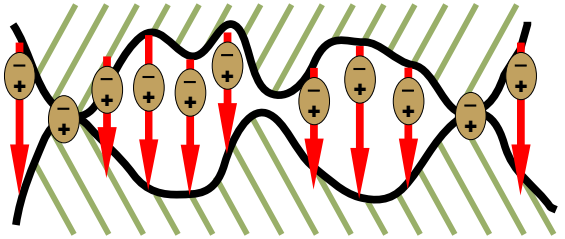
- Some conducting materials, when they come into contact, will pass electrons resulting in a difference in electrical charge between the two surfaces. This differential charge generates an electrostatic attraction, or force, between the surfaces which manifests itself as a frictional force. An analogy is the structure and operation of a simple capacitor as illustrated on the next page

Electrostatic Theory

- This schematic shows a simple capacitor; two plates separated by a dielectric material. A positive charge on one plate forces electrons to migrate to the other plate with the end result being an imbalanced charge
- Two materials in contact form this same structure. The difference is in how electrons are passed. For a capacitor, we apply an external power source. For conducting materials rubbing against one another, electron flow occurs if one conducting material binds its electrons less strongly than the other



A Simple Capacitor



Microscopic Asperities Maintain a Gap Between Surfaces Resulting in a Capacitor-like Stucture

Electrostatic Theory

- It is often thought friction effects due to electrostatic forces can be ignored. But consider this exerpt from Dominator Wax, a maker of ski wax for competitive skiing

> *"It has been discovered that static electricity can increase the friction of polyethylene (the base) on ice by 65% and the friction of metal (the edges) on ice by 40%, so clearly the elimination of static electricity is critical to achieving high speed. We have also discovered that new snow and old snow crystals generate static charges differently and require different antistatic agents. A specific micrographite blend ... is a very effective antistatic additive for new snow. Overall friction reduction is significant, although it does increase dry friction slightly ..."*

- It is easy to dismiss this as a niche application. But it does illustrate the need for more research which, in turn, could prove important to a wider range of engineering applications

1 *http://dominatorwax.com/snowfriction.html*

Chemical Bonding Theory

- The chemical bonding theory proposes that two materials in contact will form a compound at points of contact. The following is an exerpt from the Science Hobbyist[1] website

> *"Friction is mostly caused by chemical bonding between the moving surfaces; it is caused by stickiness. Even scientists once ...explained friction as being caused by "interlocking asperities", the "asperities" being microscopic bumps on surfaces. But the modern sciences of surfaces, of abrasion, and of lubrication explain sliding friction in terms of chemical bonding and "stick & slip" processes. The subject is still full of unknowns, and new discoveries await those who make surface science their profession."*

- The chemical bonding contributing to the generation of frictional force includes ionic bonding, covalent bonding, and hydrogen bonding

1 *http://amasci.com/miscon/miscon4.html#fric*

Chemical Bonding Theory

- Ionic bonds are formed when two or more atoms gain or give up electrons to form ions. This generally occurs between metals and non-metals with metals giving up the electron(s). Ionic bonds occur due to the attraction of ions with opposite charge
- Covalent bonds are quite similar except they tend to occur between non-metals. Covalent bonds differ from ionic bonds in that electrons are shared between two atoms causing the bond
- A weaker hydrogen bond is also possible. Although still the result of an attraction between particles of opposite polarity, it is formed between a hydrogen atom and a non-hydrogen, non-carbon atom such as nitrogen, oxygen, fluorine, sulfur, phosphorus, or boron (to name a few)

Adhesion Theory

- The adhesion theory of friction is a well accepted theory capable of explaining much of what we observe in practice regarding friction. Adhesion is defined as the molecular attraction exerted between bodies in contact. There are five mechanisms that define adhesion
  - Mechanical adhesion
  - Chemical adhesion
  - Electrostatic adhesion
  - Dispersive adhesion
  - Diffusive adhesion
- The first three mechanisms were previously discussed as independent theories of friction. Let us define the last two

Adhesion Theory

- Dispersive adhesion is a form of adsorption. That is, two materials may be held together by van der Waals force. A van der Waals force is the attraction between two molecules with positively and negatively charged ends. A van der Waals force tends to be a weak molecular bond. Its greatest impact on friction is that it causes the formation of a thin layer of adsorbed gas and oxide on metal surfaces. The table below illustrates the impact of this phenomena on static friction

Effect of films on coefficient of static friction			
Material	**Clean Dry**	**Thick Oxide Film**	**Sulfide Film**
Steel-Steel	0.78	0.27	0.39
Copper-Copper	1.21	0.76	0.74

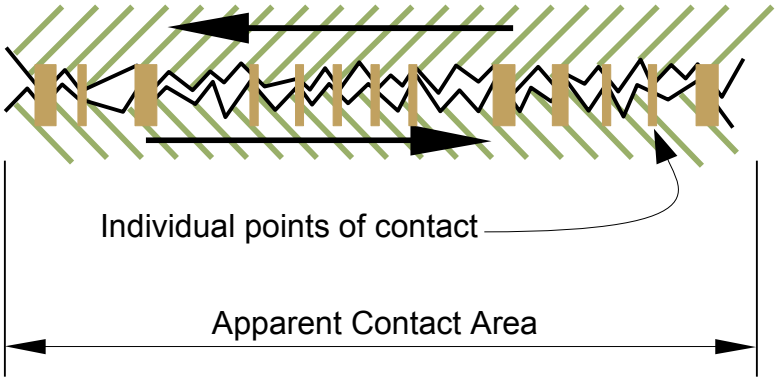
Adhesion Theory

- Diffusive adhesion may occur between two substances when the molecules of both materials are mobile and soluble in each other. This would be particularly effective with polymer chains where one end of the molecule diffuses into the other material

- The strength of adhesion between materials depends on which of the these mechanisms occur and the area over which the two materials make contact. However, this contact area is not the geometric projected area of the mating surfaces. At this point, we need to introduce the concept of apparent area of contact and real area of contact

Contact Area

- The apparent area of contact is the projected area of the object resting on a surface. However, asperities result in a significantly limited real contact area. Real area of contact is the sum of the microscopic areas measured at those points where asperities meet



- The actual contact area for common surfaces is approximately 0.01% of the projected area of contact, thus the reason friction is essentially independent of apparent or geometric area

Adhesion Theory

- Amonton's 1st law (i.e.: friction force is proportional to load) is also well served by the idea of real contact area, but only if the number of asperities in contact can be considered loading dependent. In other words, as the normal force between the two mating surfaces increases, the number of asperities in contact increases as well
- It should be noted the adhesion theory will break down for very rough surfaces and very smooth surfaces. In both cases, it is due to the fact one mechanism of adhesion begins to dominate relative to a typical material
- For example, the laws of friction tend not to apply for very rough surfaces due to the dominance of asperity interlock. Think of two pieces of course sandpaper rubbing together

Adhesion Theory

- Similarly, the laws of friction do not tend to support the interaction between very smooth surfaces. In such an instance, various forms of molecular attraction begin to dominate

Theories of Friction

- The self-healing crack theory[1] is a relatively new theory. It supposes that at the atomic scale, microscopic crack's open, then self-heal, allowing solids to slip in accordance with Coulomb's law

$$F_f = \mu \cdot F_N$$

It is assumed this theory will supplement existing theories, but it does require more research

1 "*New Theories Exposes Cracks in Laws of Friction*", Scientific American, Thursday, September 20, 2001

The Racing Tire Dilemma

- At the start of this topic, we asked the question that if friction did not depend on area, why are racing tires so wide? At the risk of oversimplifying a complex subject, the reason comes down to issues of wear, heat dissipation, and structural stability
- High-traction tires are made of very soft, sticky rubber. This sticky compound creates a high coefficient of friction for improved traction. However, this 'stickiness' results in increased adhesive wear. In order to generate acceptable life from a tire, they are made relatively wide to spread the wear over the tire area

The Racing Tire Dilemma

- Other issues that may affect tire width are those of heat dissipation and structural stability. Increased frictional forces result in more heat being generated. A wide tire will help dissipate this heat
- There is also the issue of tire rigidity under the stress of acceleration, deceleration, cornering, etc. While traction on dry pavement is strictly a function of material selection, it is these other design parameters that impact tire width
- The lesson to be learned from this discussion is not what goes into tire design, but rather that the design paramaters of any structure can have rather complex interactions. It is important to have a broad understanding of many aspects of mechanical engineering technology to develop a successful product

Summary

- It is important to note the previous discussions only dealt with friction between clean, dry surfaces and clean, partially-lubricated surfaces. It does not apply to well-lubricated surfaces
- Although the laws of friction are well accepted, an explanation to well define these laws tends to elude us. However, the current theory of adhesion seems to best define what we observe in our lives
- In practice, friction is the sum of a number of different forces. The most effective way to optimize friction is through a testing process involving the selection of materials, optimizing surface roughness, and the proper selection and application of lubrication

Development Resources

- Primary
  - http://depts.washington.edu/nanolab/ChemE554/Summaries%20ChemE%20554/Introduction%20Tribology.htm
  - http://www.roymech.co.uk/Useful_Tables/Tribology/class_Friction.html
  - http://www.goiit.com/posts/list/mechanics-cause-of-friction-is-electromagnetic-forces-between-992457.htm
  - http://www.scribd.com/doc/7202949/Mod-5
  - http://www.absoluteastronomy.com/topics/Friction
  - http://hyperphysics.phy-astr.gsu.edu/hbase/frict2.html
  - http://stevemunden.com/friction.html
  - http://www.physics.princeton.edu/~mcdonald/examples/QED/persson_prb_57_7327_98.pdf