# RUNWAY RUBBER REMOVAL

by

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**RUNWAY RUBBER REMOVAL**

## CHAPTER 1 - INTRODUCTION

1.1 The Need for Research. When the wheels of landing aircraft impact a runway pavement, they deposit rubber on the pavement surface. As deposited rubber accumulates, the available friction between aircraft tires and the runway surface is reduced. This results in hazardous aircraft operating conditions.

When the number of aircraft landings per day at an airport, the $125,000,000 price of a B747-400, and the lives of 400 to 500 passengers on board are considered, proper removal of rubber quickly becomes a morally and economically paramount safety concern.

Conversely, removing rubber deposits too often may damage the runway surface. One study (see paragraph 2.9) has shown that rubber removal contracts are effective in increasing tire-pavement friction only 40% of the time. In fact, the same study demonstrates improper removal techniques may actually decrease tire-pavement friction.

1.2 The Goal of The Research. Determining the optimum time to remove runway rubber accretions is an ongoing concern.

In this research report, factors affecting the need, method, and timing of rubber removal are addressed.

1.3 <u>The Method of Research.</u> A literature review first investigates the history, mechanics, components, and factors bearing on tire-pavement friction. Then, runway rubber removal is examined including: persons involved, methods of measurement, frequency of removal, methods of removal, and effectiveness of removal.

Completed questionnaires from pilots, airport operations managers, and airport maintenance superintendents at the major United States airports are also examined. The questionnaires explore normal airport operations, how runway rubber accretions are identified, how concerned parties become involved, how runway rubber is removed, and the effectiveness of rubber removal operations. Responses are presented in tabular format.

## CHAPTER 2 - LITERATURE REVIEW

### PART I - TIRE-PAVEMENT FRICTION

2.1 Mechanics of Tire-Pavement Friction. The mechanics of tire-pavement friction are fundamental to any study of the runway rubber process. In this section the history and two main components of friction are reviewed. Terms introduced in the history section are defined later in the report.

2.1.1 History. In ancient times the Egyptians, Greeks, and Romans knew about friction and were aware of the need for lubricants. During the Renaissance, approximately 1508, Leonardo da Vinci considered friction in his writings and speculated that friction is proportional to load [1,2]. In more modern times Guillaume Amontons first proposed the two main laws of friction. In 1699, Amontons suggested that friction force is proportional to normal force and that friction is independent of the size of the bodies in contact. Amontons also attributed the cause of friction to surface roughness. That is, he saw frictional resistance as the force required to lift one rigid surface over the asperities of another surface [1,2]. In 1724, Jean Theophile Desaguliers observed that adhesion is a component of friction [1]. Then in approximately 1779, Charles Augustine Coulomb began to investigate friction. In his 1781 paper, Theory of Simple Machines, Coulomb determined that the following parameters were important in friction: "nature of materials in contact and their coating; the surface area; the normal force; time of repose; relative velocity" [2]. Coulomb considered the work of Desaguliers on adhesion but rejected the idea. He felt friction developed from a surface lifting over asperities, and the asperities bending and breaking; he considered surface cohesion a negligible factor [1]. Samuel Vince, in 1785, rejected the notion that friction is proportional to load and said friction does, to some extent, depend on the size of the bodies in contact. Vince defended surface cohesion as a factor in friction [1]. In 1804, John Leslie took a negative attitude toward adhesion while trying to explain the energy loss in friction. Further developing on the surface asperity theory, Leslie said friction arises from deformation losses in the sliding interface of two bodies; this is now called "ploughing effect, plastic displacement or, in the case of elastic solids, hysteresis losses." [1] The debate over the proportions, or even existence, of adhesion and hysteresis components in surface friction continued. Ewing (1892), Hardy (1936), and Tomlinson (1929) were influential proponents of adhesion [1], while Bikerman defended the views of Coulomb [3]. Bowden and Tabor (1954) [1], and many others [4,5] since, agree that both adhesion and hysteresis components of friction do exist.

In the area of tire-pavement friction, there has been interest since the late nineteenth century [6]. Researchers recognized that the coefficient of friction was greater when sliding was impending versus during sliding [7]. In the 1920's, T.R. Agg performed research on pavement slipperiness at Iowa State College. Agg sprayed water on the ground, then pulled a locked-wheel car, outfitted with a mechanical recorder, over the wet ground. From his tests, Agg determined that, "the coefficient of friction as measured in these investigations <in the field> is apparently the factor the engineer must deal with in problems of design" [7]. With the proliferation of the automobile and expansion of the road network came an increased awareness of the need for adequate tire-pavement friction. In 1958, the first international skid prevention conference was held. And in 1959, the American Society for Testing and Materials (ASTM) established Committee E-17 to investigate skid resistance [6].

While automobile traction was gaining attention, aircraft traction was not being ignored. The National Aeronautics and Space Administration (NASA) took the lead in studying aircraft tire-pavement friction. In 1954, NASA put the Langley landing-loads truck into operation to simulate aircraft landing on runways. In 1956, the initial hydroplaning studies were performed [6]. Interest in aircraft skid resistance was boosted by the introduction of heavier, faster commercial jet aircraft in the late '50's. Some of the achievements in aircraft tire-pavement research are listed below:

1960 NASA began research on aircraft braking performance on dry and wet runway pavements of various textural and groove configurations [8].

1965-67 Correlation between profile tracing devices/outflow meter/sand patch test (surface texture measurement methods) and skid resistance gradient established [9].

1967 Landing research runway completed at NASA Wallops Station [6].

1968 Pavement grooving studied by NASA [6,8]. NASA, Federal Aviation Administration (FAA), and British Ministry of Technology attempted to relate the test results of various friction measuring devices to actual aircraft braking performance, thereby allowing establishment of a standard critical value below which measured friction should not fall [6,10].

1970 Modified sand patch test found to have poor repeatability and poor correlation with skid resistance [9].

1972 Part 139 of the Federal Aviation Regulations (FAR), adopted. In part, this required certificate holders to remove airfield pavement contaminants (including rubber) as promptly and as completely as practicable [11].

1978-80 FAA conducted friction and pavement evaluation surveys at 268 airports (491 runways) within the contiguous United States [12].

1982-85 FAA conducted a series of tests and found the Mu-Meter, Saab Friction Tester, Skiddometer, and Runway Friction Tester all reliable; FAA also established correlation values between the four devices [8].

1983 FAA Technical Center study determined the optimum groove dimensions [8].

1983-86 NASA study correlated friction measuring devices and aircraft braking action on ice- and snow-covered runways [13].

Tire-pavement friction, like friction in general, has been the subject of some disagreement. The interaction of a viscoelastic material tire with a relatively rigid pavement surface does not accord with the classical laws of friction [4,14]. Most now feel that adhesion is the greater of the two main components of surface friction [4,5,15,16]. However, there are still some who contend, with Coulomb, that adhesional forces are negligible and that hysteresis forces predominate in surface friction - especially when rolling viscoelastic materials are involved [17,18].

2.1.2 Adhesion and Hysteresis. A pavement surface may appear smooth, when it is actually characterized by undulations and asperities. As a rubber, or elastomer, surface passes over the pavement, the elastomer drapes over the pavement asperities (see Figure 1).

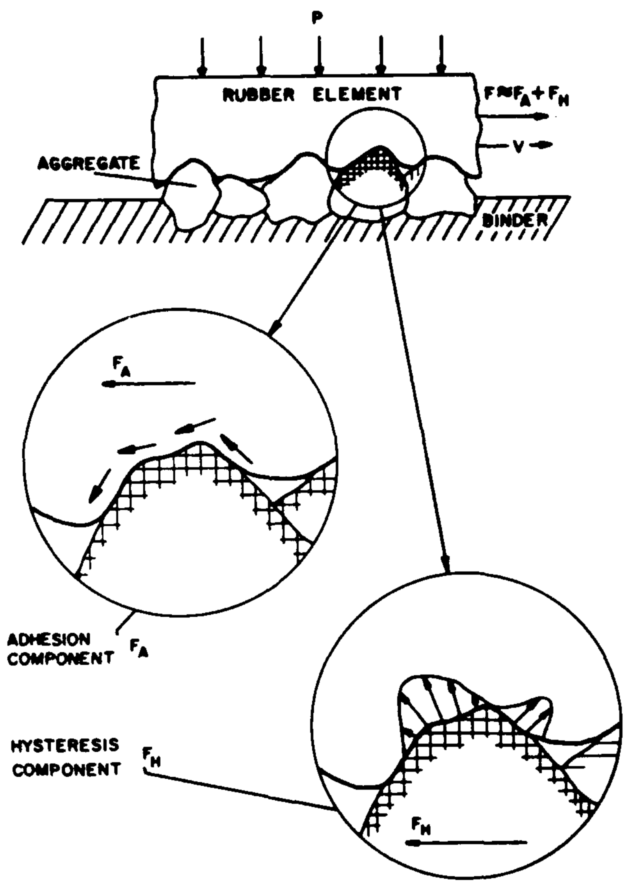



Figure 1 Principal Components of Elastomeric Friction [14]

The area of contact between elastomer and asperities is proportional to the normal force [19].

"If a force F is now applied tangentially to the upper surface, relative motion at the frictional interface takes the form of a 'flowing' action as the elastomer conforms to the asperities of the base. A frictional force equal in magnitude and opposite in direction to the applied force F is generated at the sliding interface, and it includes both adhesional and hysteresis components, thus: F=F(adh)+F(hys)" [4].

Adhesion occurs at the contact points because molecules on the opposite surfaces "are so close together that they exert strong intermolecular forces on each other" [19]. In effect, the molecules on opposite surfaces bond. As a tire rolls, the bonds are stretched and broken. Thus a "dissipative stick-slip" molecular process is fundamentally responsible for adhesional friction [4,19]. The physical laws governing this phenomena have yet to be discovered [10].

Another name for the hysteresis component of tire-pavement friction is bulk internal friction [18]. As an elastomer moves relative to the pavement asperities, it tends to "'accumulate' or 'pile up' at the leading edge of the asperity and to break contact at a higher point on the downward slope" [4]. An unsymmetrical pressure distribution results (see Figure 1) where the horizontal pressure components oppose the sliding motion. Energy is dissipated within the rubber bulk due to stress relaxation [10].

Theoretically, on a clean, dry plate glass surface with no deformations, F=F(adh). On a well-lubricated irregular surface, where the lubricant makes shear strength of the contact area trivial, F=F(hys) [14].

Many other complicating factors cloud the investigation of tire-pavement friction. Analysis in sterile laboratories cannot duplicate the myriad interacting effects on tire-pavement friction of pavement, tires, drainage, aircraft characteristics, pilot techniques, climate, and contaminants. Further investigation is needed to fully understand the mechanics of aircraft rolling tire-pavement friction.

2.2 Pavement. Fundamental to tire-pavement friction is the texture of the pavement. Other pavement characteristics will also induce changes in the achievable amount of surface friction.

2.2.1 Texture. Pavement textures may appear smooth, but actually are characterized by undulations and asperities. The texture can be broken into two sub-groups; macrotexture, or macro-roughness, and microtexture, or micro-roughness (see Figure 2).

2.2.1.1 Macrotexture. Macrotexture is the visible "surface relief of the pavement" [16]. On an asphalt pavement this is the aggregate, while on a portland cement concrete pavement it is the surface finish. By definition, macrotexture has a wavelength and amplitude of 0.5 mm or more [21]. The main function of the macrotexture is to permit the escape of water from under the tire [15,16].

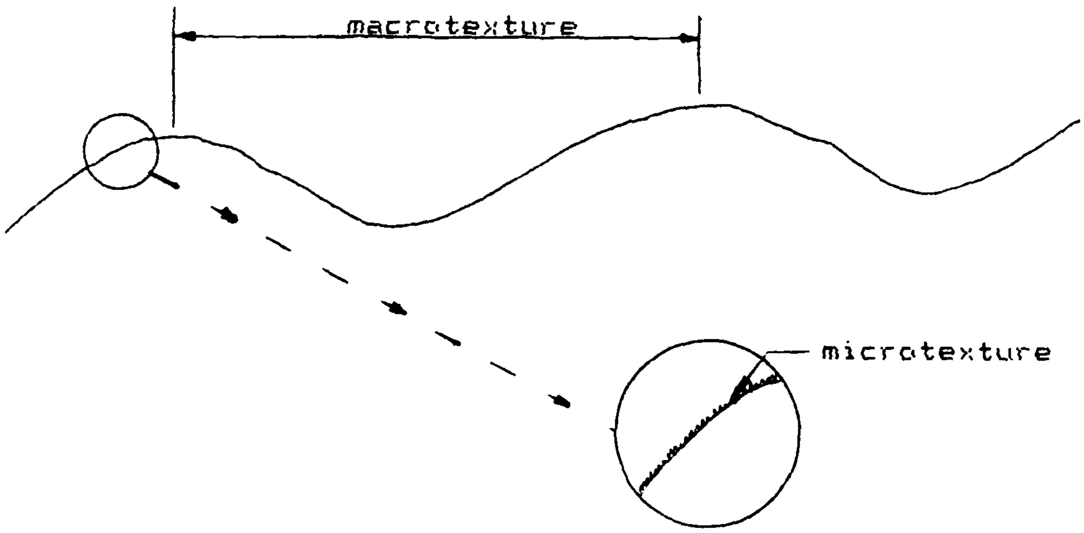



Figure 2 Pavement Macrotexture and Microtexture [4]

2.2.1.2 Microtexture. Microtexture refers to "the fine-scale roughness contributed by small individual asperities of aggregate particles on pavement surfaces which are not discernible to the eye but are apparent to the touch" [8]. By definition, microtexture has a wavelength and amplitude of less than 0.5 mm [21]. Microtexture largely affects the adhesion component of tire-pavement friction. On a wet pavement the microtexture penetrates a thin layer of water, allowing adhesion between the tire and pavement.

2.2.2 Other Pavement Characteristics. Several factors influence a pavement's macro- or micro-texture. Pavement type, construction techniques, condition, and drainability all play a role in tire-pavement friction. Runway pavements are normally constructed of portland cement concrete (PCC) or asphalt concrete (AC). Grooves or a porous friction course (PFC) are sometimes added to the pavement structure to assist the macrotexture in water drainage.

2.2.2.1 <u>Portland Cement Concrete (PCC) Pavement.</u> In a PCC pavement, macrotexture is developed by texturing in "ridges of fine mortar and aggregate" [8]. The FAA recommends fine aggregate (sand) and an average texture depth of 0.025 inches (0.25 mm) to provide an adequate friction surface [8]. If the pavement macrotexture is low, water may build up at the tire-pavement interface, obscuring the microtexture and decreasing tire-pavement friction. (Water build-up at the tire-pavement interface will be discussed more in a later section.) During construction, while the concrete is still in a plastic condition, texture can be constructed into the PCC pavement by finishing with a natural-bristle paving broom, heavy burlap drag, wire brushes, wire combing, or a fluted magnesium float [8,15]. The best time to texture a PCC pavement is during construction, "when the water spots have dried enough to ... hold the texture but before the drier spots have dried too much to texture" [8]. Immediately after texturing, "application of the curing compound assures that the pavement surface will not lose water and cure too rapidly"

[8]. If the surface dries too quickly, mortar ridges will not set up properly leading to reduced durability and faster loss of skid resistance [8].

2.2.2.2 Asphalt Concrete (AC) Pavement. In an AC pavement, the coarse and fine aggregate create an illusion of adequate macro- and micro-texture. In truth, "due to the 'smoothing' effect of rolling equipment, the coarse aggregate rarely penetrate above a thin film of water" [8]. Given normal quality control methods are used, there is not much that can be done during construction to improve AC surface friction [8]. In design, soft aggregate and excessive binder should be avoided. Excess binder may cause the pavement to bleed, coating the microtexture and thereby reducing tire-pavement friction. Soft aggregate will polish, that is the microtexture will be worn off, again reducing tire-pavement friction [8,15,16]. The FAA recommends large, angular aggregate such as unweathered, crushed quartzite, quartz diorite, granodorite, and granite-rocks high in silica (versus aggregate high in carbonate) [8]. The "presence of coarse grain sizes and gross differences in grain hardness appear to combine and lead to differential wear and breaking off of grains" [8] leading to a constantly renewed abrasive surface. Various methods are available for providing and restoring macrotexture in AC pavements. Possibilities include: chip seals, aggregate slurry seals, cold milling, Porous Friction Course (PFC) overlays, and grooving [8,22].

2.2.2.3 Drainage. Increasing a pavement's drainage capability means a dryer tire-pavement interface and increased surface friction. The FAA recommends a transverse slope on runways of at least 1.5% for effective drainage [8]. PFC overlays and grooving are two common airport techniques for increasing a pavement's drainability. The advantage of these two techniques is that, in themselves, they increase the pavement macrotexture in addition to accentuating microtexture through improved water runoff.

2.2.2.3.1 Porous Friction Course (PFC) Overlay. A PFC overlay is a thin asphaltic overlay - usually 1-1.5 inches (25-38 mm) thick [8]. The pavement is made porous by increasing the percent of voids and using a high proportion of uniform-sized aggregate with little filler or binder [16]. On a porous overlay, water that does not run off will flow through the surface and drain off transversely, allowing the tires to interface with the pavement microtexture [8,15,16]. The FAA does not recommend PFC overlays for runways with greater than 450 aircraft operations per day [8]. Rubber deposits and contaminants can accumulate in pavement voids, significantly reducing the overlay's drainage capability [8].

2.2.2.3.2 Grooving. It is common at airfields to transversely groove the runway surface. Initially, grooved pavements were responsible for chevron-type cuts and chipping in tires [23]. Adjustments in aircraft tire design were made to eliminate this type of tire distress. In fact, now it is reported that "grooved pavements accumulate less rubber for a given amount of usage than ungrooved pavements" [12]. Grooved pavements remove bulk water from the runway, thereby allowing the pavement macro- and micro-texture to interface with aircraft tires. An aftereffect of grooves is, in themselves, an increased macrotexture. Both NASA and FAA studies showed a high level of friction was maintained by using 0.25" x 0.25" (6 mm x 6 mm) grooves, 1.5" (38 mm) apart; this is now the standard FAA configuration [8]. The FAA has found that grooves need not extend to the runway edge to be effective [8].

2.3 Tires. Diverse elements play a role in the tire portion of tire-pavement friction. Tire material, tread pattern, type, pressure, and wear/aging are the primary constituents.

2.3.1 Material. Some properties of five common synthetic rubbers used in tire construction are depicted in Figure 3.

By altering the tire material mix, manufacturers can greatly influence tire-pavement friction. Peterson et. al., for example, found that vehicles with a BR-type rubber tire required 180 feet to stop (on a wet asphalt road), while a butyl-type rubber tire stopped within 130 feet. They found that "a softer rubber will be deformed more by a given asperity, and a high-hystersis rubber will be capable of absorbing a greater percentage of the energy produced in such deformations" [5]. In other words, tires with soft, high-hystersis rubber will improve traction.

| Type of Synthetic Rubber | Abbreviation | Properties |
|---|---|---|
| Neoprene | CR | High tensile strength<br>Good resistance to ageing and weathering<br>Poor bonding to carcass fabrics |
| Styrene-Butadiene | SBR | Excellent abrasion resistance<br>High hysteresis<br>Good resistance to cracking<br>Strong bonding to carcass<br>Poor tear and cutting resistance |
| Polybutadiene | PB or BR | Very stable over wide temperature range<br>Good wear resistance<br>Strong tear and cutting resistance<br>Poor wet traction |
| Butyl | IIR | Low gas permeability<br>High hysteresis<br>Good traction characteristic<br>Poor affinity for blending |
| Polyisoprene | PI | Strong wear resistance<br>Very similar to natural rubber<br>Low sensitivity to heat build-up |

Figure 3 Some Properties of Synthetic Rubber Materials [4]

2.3.2 Tread Pattern. Tread pattern plays an important role in tire-pavement friction when pavements are lubricated. When a pavement is dry, the best tread pattern is no tread design at all; that is, the greatest amount of surface contact possible is desired [Kienle in 5]. When a pavement is lubricated, the tire tread pattern acts to remove the lubricant, thus enabling tire-pavement contact/friction.

The variety of automobile tread patterns promoted to increase tire-pavement friction is nearly innumerable. Aircraft tires, on the other hand, usually utilize a simple longitudinal rib pattern.

2.3.3 Type. For automobiles, radial-ply, conventional bias-ply, and combination tires are available. In recent years radial-ply tires have come to dominate the automobile market. Radial-ply tires offer advantages in increased tire-pavement friction through greater surface contact area. The breaker belt in radial-ply tires allows a "relatively uniform and constant ground pressure" [4] over the whole tire-pavement contact area, compared to the bias-ply tire. The radial-ply tire also deflects more under load, further increasing the tire-pavement contact area [4].

Aircraft tires undergo extreme loading conditions. As Henry Schwerdtfeger of Michelin stated, "An aircraft tire must handle three times the speed, four times the load, two times the tire pressure and three times the deflection in comparison to a radial truck tire" [24]. Or as Joseph Gengo of Goodyear more succinctly said, an aircraft tire must handle the "speed of a racing tire and ... the load of an earthmover" [24]. Bias-ply tires have long been the standard for aircraft tires. Problems with chevron-type cuts and chipping in the tires, associated with runway grooving, were reduced by the use of tire performance specifications and fabric-reinforced tire treads [10].

Lately, Goodyear, Goodrich, and Michelin have introduced radial-ply tires to the aircraft industry [25]. In 1984 a Michelin spokesman went so far as to predict, "in 10 years the majority of the market will be radials ... same pattern as car and truck markets" [26]. Radial-ply tires for aircraft are advertised as having handling similar to bias-ply tires, while offering a 20-30% tire weight reduction, increased load carrying capability, improved cut resistance, 2-5% improved traction, cushioned takeoffs/landings, and increased tread and tire life (reduced interply friction leads to less heat build-up, which allows increased life potential; also, tread wear is more even) [26,27,28,29]. One manufacturer estimated that the enhanced payload potential on a B-747 would yield an additional $1,000,000 in revenue per year per aircraft [30]. The certification process in America is lengthy and costly, but hopes for the future of aircraft radial-ply tires are high. The French DGAC civil aviation authority has already certified radials for use on Airbus A 310-200 and A 310-300 transports [31].

2.3.4 Pressure. Tire pressure is a delicate issue when it comes to tire-pavement friction. Increased tire pressure shrinks the tire-pavement contact area and allows water to escape easier. A higher tire-pavement pressure also discourages entrapped water at the tire-pavement interface. In wet conditions, this permits greater traction. Conversely, in dry conditions, decreased tire pressure increases the tire-pavement contact area and, therefore, tire-pavement friction [32]. Aircraft personnel are more concerned about traction in wet conditions, and as a result, aircraft tires are designed for high tire pressures. Commercial aircraft, for instance, typically have main truck assembly tire inflations of about 180 psi [33].

2.3.5 Wear/Aging. Tire wear/aging is affected by the manufacturer, user, and environment. Manufacturers can alter tire materials to increase wear resistance. Users can prolong tire life by diligent maintenance: proper pressure, balance, alignment, and timely retreads. If the user lets his tires wear unevenly or excessively, the tire tread pattern will be ineffective in removing lubricants, tire-pavement contact area will be reduced, and available friction will be lowered. Pavement surface defects, chemicals, and the sun all may work together to prematurely age a tire.

2.4 Miscellaneous Factors. Items which affect tire-pavement friction are legion. This section investigates some of these factors, including: contaminants, speed, temperature, and seasons.

2.4.1 Contaminants. As noted in earlier sections, adhesion is a very important component of tire-pavement friction. Since adhesion is largely controlled by a pavement's microtexture, anything that diminishes a pavement's microtexture will reduce tire-pavement friction and create unsafe conditions. Contaminants such as water, snow, ice, slush, dust, sand, mud, organic debris, fuel, oil, grease, chemicals, and rubber deposits may lodge in/over the pavement asperities, obscure the microtexture, and act as a crude lubricant to prevent tire-pavement friction [8,20]. Figure 4 illustrates the effect of contaminants on the adhesion (fA) and hysteresis (fH) components of friction.

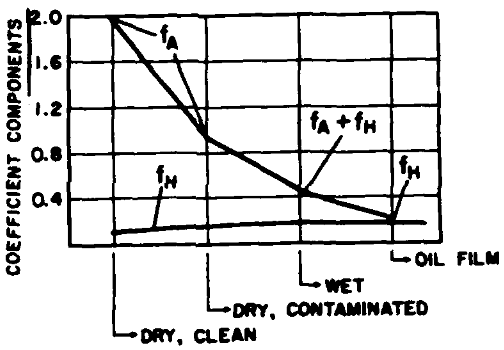



Figure 4 Contaminants v. Coefficient Components [14]

This subdivision explores in more detail the water and rubber deposit contaminants.

2.4.1.1 <u>Water.</u> When a tire travels over a wet pavement at high speeds, the tire-pavement contact is reduced. Water is unable to quickly escape from under the moving tire and an incompressible wedge forms, lifting the tire from the pavement [9] (see Figure 5).

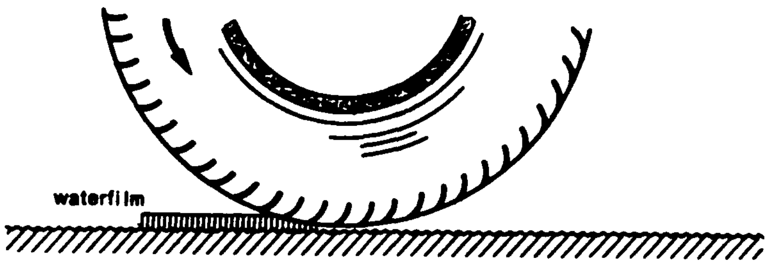



Figure 5 Contact Areas Between Tire and Road Surface [16]

If the tire tread, pavement macrotexture, and slope do not remove enough water from the tire-pavement interface, friction will be nil and dynamic hydroplaning will occur [34]. Also possible are viscous hydroplaning (where a "thin film of fluid remains between tire and pavement since there is insufficient pavement microtexture to promote its breakdown" [34]) and tire tread reversion skidding (which "occurs at high speeds on wet pavement with macro but little microtexture ... heat buildup due to sliding causes rubber to revert and melt ... slides along on cushion of molten rubber, water and steam" [34]). See Figure 6.

2.4.1.2 Rubber Deposits. When aircraft tires impact a runway pavement, "a certain amount of rubber is transferred from the tire to the pavement as a result of heat and abrasion produced when the aircraft tires spin-up" [10]. Rubber "first coats the finer microtexture, then occludes the macrotexture as rubber build-up increases" [36]. Rubber coating the microtexture changes sharp asperities to rounded

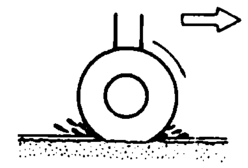
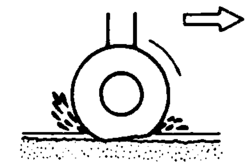
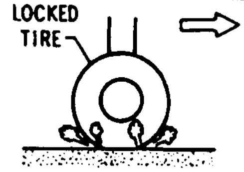
| | HYDROPLANING | | REVERTED RUBBER SKIDDING |
|---|---|---|---|
| | VISCOUS | DYNAMIC | |
| CAUSES |  |  |  |
| CONTRIBUTING FACTORS | DAMP OR WET PAVEMENT<br>MEDIUM TO HIGH SPEED<br>POOR PAVEMENT TEXTURE<br>WORN TIRE TREAD | FLOODED PAVEMENT<br>HIGH SPEED<br>LOW TIRE PRESSURE<br>WORN TIRE TREAD | WET OR FLOODED PAVEMENT<br>HIGH SPEED<br>POOR PAVEMENT TEXTURE<br>DEFICIENT BRAKE SYSTEM |
| ALLEVIATING FACTORS | PAVEMENT MICROTEXTURE<br>PAVEMENT GROOVING<br>GOOD TREAD DESIGN | PAVEMENT MACROTEXTURE<br>PAVEMENT GROOVING<br>INCREASED TIRE PRESSURE<br>GOOD TREAD DESIGN | GOOD PAVEMENT TEXTURE<br>PAVEMENT GROOVING<br>IMPROVED ANTISKID |

Figure 6 Principal Causes of Wet Pavement Tire Friction Losses [35]

spheres which cannot generate the hydraulic pressure necessary to penetrate the thin viscous films of water on a wet runway [36]. Thus dry tire-pavement contact and, therefore, adhesion are constrained. If rubber continues to increase until the macrotexture is occluded, bulk water drainage is impeded and hydroplaning is further encouraged.

When tires go from rotating at zero velocity to rotating at touchdown velocity, immediately following touchdown, it is known as "spin-up" [37]. In aircraft brake design, braking efficiency is reduced if tires do not move at the same velocity as the aircraft [37]. When aircraft tires are unable to fully spin-up due to insufficient friction, then aircraft braking is impaired and safety becomes a key concern.

Among other things, rubber accretion is a function of the number of aircraft landings [10]. MacLennan, et.al., found that "runways with landings less than 250 million pounds <aircraft landing weight> per year rarely have significant rubber accumulation" and of runways with no record of rubber removal, very few had landings with greater than 5,000 million pounds per year [12].

2.4.2 Speed. In tire-pavement friction, "microtexture provides frictional properties for aircraft operating at low speeds and macrotexture provides frictional properties for aircraft operating at high speeds" [8]. Figure 7 graphically portrays the relationship of velocity to the adhesion (fA) and hysteresis (fH) components of tire-pavement friction.

Small general aviation aircraft are able to exit runways more quickly because their slower landing speeds allow greater initial tire-pavement friction. Modern jet aircraft, with their higher operational speeds and heavier gross weights, require high shear forces generated at the tire-pavement interface for safe operation [36]. A quick glance at Figure 7 shows the limited amount of friction available to high speed aircraft in favorable conditions; safely stopping an aircraft on a short, wet, and windy runway can be a problem [38]. Light jet aircraft (business jets, military fighter planes) especially find it difficult to taxi off such a runway over slick rubber deposits.

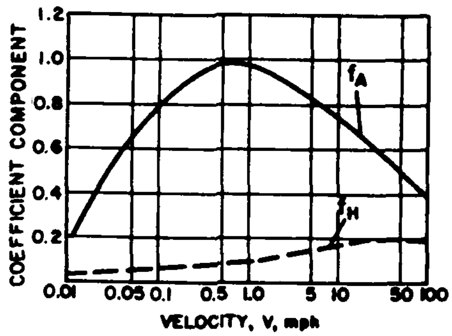



Figure 7 Velocity v. Coefficient Components [14]

2.4.3 Temperature. Ambient, tire, pavement, and water temperatures all play a role in tire-pavement friction. High ambient temperatures warm tires, pavement, and water. The increase in molecular motion at the tire-pavement interface induces a drop in both the adhesion (fA) and hysteresis (fH) components of tire-pavement friction (see Figure 8) [14].

This drop is chiefly due to the inverse relationship of adhesion and hysteresis to the amount of energy stored in a tire [4]. Moore says, "both the tensile strength of natural rubber and cord/rubber adhesion" decrease with increasing temperature [4]. Thus, theoretically, when higher ambient, pavement, and water temperatures increase a tire's internal temperature, tire-pavement friction is reduced. Pavement and water temperature significantly impact surface friction. MacLennan, et. al., found variations as high as 8 Mu Numbers (MuN - refers to the coefficient of friction as measured by a Mu-Meter) on the same surface, depending on the pavement and water temperature [12]. Specifically, they found that friction decreases with increasing water temperature at a rate of 0.5 MuN per degree C. Surprisingly, they reported friction increases with increasing pavement temperature at a rate of 0.2 MuN per degree C [12].

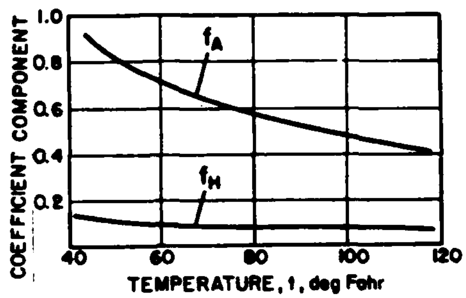



Figure 8 Temperature v. Coefficient Components [14]

2.4.4 <u>Seasons.</u> Tire-pavement friction fluctuates with the seasons. Studies in the United Kingdom and Kentucky disclosed an annual sinusoidal cycle, based on seasonal variations [16,39] (see Figure 9).

As measured by skid number, tire-pavement friction is generally at a maximum in late winter/early spring and at a minimum in late summer [39]. There are several reasons for this trend. In summer, dust and other contaminants inhibit tire-pavement adhesion. In winter, rains wash contaminants from the pavement [16,20]. And, as an observation: rubber is not deposited as readily on wet pavements and snow removal equipment, used at northern climate airports, partially scrapes off rubber deposits.

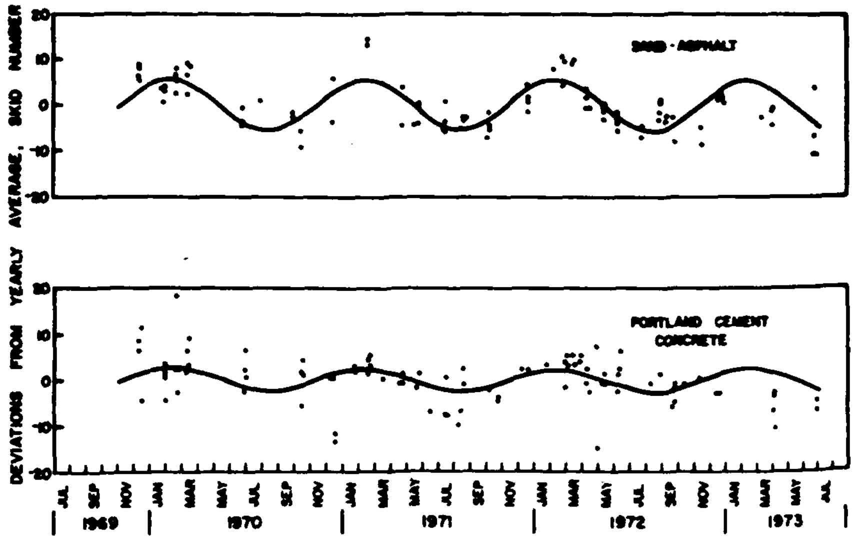



Figure 9 Seasonal Variation of Skid Number Over Several Year Annual Variations As a Function of Season and Traffic (Best Fit Curves) [39]

Though not affecting tire-pavement friction, wind is a factor pilots must contend with in landing an aircraft. Wind varies with season and geography for a location. Since pilots fly into many different airports in all seasons, wind rapidly becomes a complex issue. NASA in a 1979 technical publication said, "Operation of a crosswind landing gear on slippery runways needs further study, analysis, and testing. The application of antiskid braking systems also needs further study because of the variations in vertical load on the landing gear in strong crosswind conditions" [40].

# PART II - RUNWAY RUBBER REMOVAL

2.5 Runway Rubber Removal Variables. At least three different groups of individuals are normally involved in an airport's effort to increase runway tire-pavement friction through rubber removal: pilots, operations, and maintenance. Personnel in each of the three groups tend to read the same literature, attend the same seminars, encounter similar work situations, and be conversant with their peers. Theoretically, the FAA does not dictate how or when to remove runway rubber. As autonomous entities, airports are responsible for the removal of runway rubber accretions.

2.5.1 Pilots. Pilots are the runway "users." Yager [35] compiled an elegant list of the factors affecting an aircraft wet runway performance (see Figure 10).

To this list one could add lighting, runway length, and runway width. This is a lot for pilots to deal with. Any decrease in tire-pavement friction because of rubber accretions just makes matters worse. Pilots report tire-pavement friction in terms of braking action - excellent, good, marginal, or poor [13].

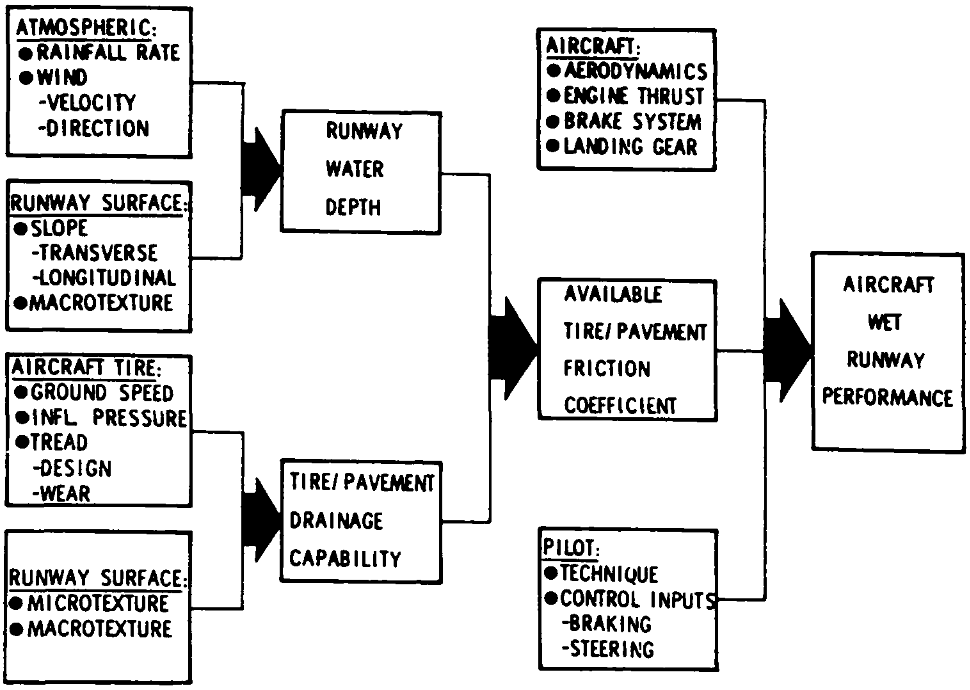



Figure 10 Factors Affecting Aircraft Wet Runway Performance [35]

2.5.2 <u>Operations.</u> As the process of runway rubber removal has evolved, operations is responsible for monitoring and removing rubber deposits. According to FAR Part 139, Section 139.305 (a)(4), "(a) Each certificate holder shall maintain, and promptly repair the pavement ... as follows: (4) ... rubber deposits, and other contaminants shall be removed promptly and as completely as practicable" [11]. In an advisory circular on self-inspection programs, the FAA identifies items that airport operators should include in their self-inspection program. The advisory circular states, "check markings for ... obscurity due to rubber build-up" [41]. In their inspections, FAA representatives insure compliance with this guidance.

2.5.3 <u>Maintenance.</u> Often, but not always, maintenance is tasked with removing runway rubber accretions. They accomplish this mission with in house forces and/or contracted forces.

2.6 <u>Measurement of Friction.</u> In times past, approaching aircraft pilots might be told the depth of water on the runway [42]. The general perception was that wet friction approximately equaled 50 percent of dry friction [43]. But "pilots were not satisfied with receiving values of water depth since they had no realization of the significance of such information and could not correlate the given values of water depth to traction coefficients or to the potential for hydroplaning" [42]. Reliable devices are now available for measuring runway tire-pavement friction; most of them are quite expensive and require highly trained personnel [8]. These friction measuring devices are only common at major airports. A multitude of less costly surface texture measurement methods are available with varying levels of reliability. There have been attempts to correlate aircraft, friction measuring devices, and surface texture measurement methods with one another. The goal has been to provide all airports with a quick, simple, reliable, inexpensive way to measure runway tire-pavement friction, so rubber accretions can be safely and economically removed. The devices, methods, and correlation attempts are covered in this section.

2.6.1 Friction Measuring Devices. Friction measuring devices can be lumped into three categories: non steady-state sliding devices, steady-state sliding devices, and steady-state slip devices [14].

2.6.1.1 Non Steady-State Sliding Devices. Non steady-state sliding devices measure tire-pavement friction as a function of energy loss. Example devices are the British Pendulum Tester (for small localized areas or laboratory work) and Diagonally Braked Vehicles (DBVs) [37].

2.6.1.2 Steady-State Sliding Devices. Steady-state sliding devices measure tire-pavement friction by pulling a wheel over the pavement surface while repeatedly braking the wheel to a fully locked position [16]. Example devices are the ASTM skid trailer and Penn State Drag Tester (for small localized areas) [37]. Most highway department friction measuring devices fall into this category.

2.6.1.3 Steady-State Slip Devices. Steady-state slip devices measure tire-pavement friction by dragging a constantly slipping wheel over the pavement surface. These devices are "better for measurements on runways because aircraft have anti skid devices to operate in the slip range around the critical (or incipient) braking coefficient that such a tester measures" [14]. Example devices are the Mu-Meter, Skiddometer, and Saab Friction Tester [37].

2.6.1.3.1 Constant Reference Side Slip. Devices like the Mu-Meter operate at a constant side slip (yaw) angle of approximately 15 degrees [16]. That is, the test wheels are mounted 7.50 +/- 0.75 degrees outward from the centerline of the Mu-Meter [44]. At this angle, the device measures the lateral force or corner friction coefficient [16,44]. The Mu-Meter produces very repeatable results; the standard deviation is approximately 2 MuN [10]. Since its introduction to NASA in 1968 [6], the Mu-Meter has been widely used in America. The FAA bases its runway tire-pavement friction survey measurement parameters on the Mu-Meter [8]. It must be remembered, though, that "the true relationship of how the Mu-Meter relates to aircraft, or whether or not side force friction is the correct or most critical quantity to measure has yet to be determined" [10].

2.6.1.3.2 Constant Longitudinal Reference Slip. Devices like the Skiddometer and Saab Friction Tester (derived from the Skiddometer BV-11 [16]) operate with wheels at a reference slip of approximately 15 percent [16]. Equipment of this type offer the advantages of more uniform tire wear, continuous testing, and easy data processing [16].

2.6.1.4 FAA Approved Devices. The FAA has approved the four following friction measuring devices: Skiddometer BV-11 Trailer, M6800 Runway Friction Tester Van (also known as the KJ Law Friction Tester), Mark IV Mu-Meter Trailer, and Mark II Saab Friction Tester Automobile [45]. Correlation values for the four devices have been established [8].

2.6.2 Surface Texture Measurement Methods. "It is now generally agreed that the skid resistance of a pavement is fundamentally controlled by the surface texture characteristics" [46]. Therefore, if macrotexture measurements at one speed "can predict skid resistance at another speed from test results" [47], a quick, simple, reliable, and inexpensive test may be realized. Figures 11-13 list most of the known surface texture measurement devices compiled under the designations: direct profile measurement methods (see Figure 11), direct texture measurement methods (see Figure 12), and indirect texture measurement methods (see Figure 13) [46].

In Volume IV (pages 13-38) of their thorough report, Harwood, et. al., [22] give a succinct description of the 28 most commonly or recently used surface texture measurement methods. Without a friction measuring device or surface texture measurement method, airport operations and maintenance personnel must rely on visual interpretations of when to remove runway rubber or other contaminants to assure adequate tire-pavement friction. FAA AC No: 150/5320-12A, Reference 8, outlines a visual surface measurement method.

1. Silicone casting

2. Macrotexture profile tracing
   a. Profilograph or profilometer
   b. Modified versions of the profilograph
   c. University of New South Wales unit
   d. Linear traverse device
   e. Texturometer/Rainhart Text-Ur-Meter

3. Microtexture profile tracing
   a. Profilograph or profilometer
   b. Gould Surfanalyzer
   c. Surfindicator

4. Stereophoto-interpretation mapping

5. Non-laser light stylus
   a. Vertically projected narrow light beam
   b. Zero-slope detector

6. Laser light stylus
   a. TRRL contactless sensor
   b. Modified TRRL contactless sensor
   c. Autech Laser Dimension Gage Models 2DSLT6 and .5DSLT3

7. Line of light (Goodman) method
   a. Maryland vidicon system
   b. KLD optical rail wear inspection system
   c. Ensco photographic line of light system

8. Shadow interpretation
   a. Ontario Highway Department system
   b. Photoestimation

Figure 11 Direct Profile Measurement Methods [46]

1. Sand-patch methods
   a. Simple sand patch
   b. Modified sand patch
   c. Vibrating sand patch

2. Sand track

3. Grease patch

4. Putty impression
   a. Simple putty impression
   b. Modified putty impression

5. Schonfeld method

6. Laser light stylus
   a. TRRL contactless sensor
   b. Autech Laser Dimension Gage Model 2DSLT6

Figure 12 Direct Texture Measurement Methods [46]

1. Outflow meter
   a. Static drainage method
   b. Pressurized drainage method

2. Tire noise
   a. Microphone mounted on a moving vehicle (near-field measurement)
   b. Stationary microphone located by roadside (far-field measurement)

3. Ribbed versus blank tire skid test

4. Light depolarization

5. British pendulum tester

6. Penn State University drag tester

7. White light speckle

Figure 13 Indirect Texture Measurement Methods [46]

2.6.3 Correlation Attempts. Investigators have attempted to correlate aircraft braking action with friction measuring devices, and friction measuring devices with surface texture measurement methods.

2.6.3.1 Aircraft Braking Action v. Friction Measuring Devices. In a three-year study, Yager, et. al., sought to correlate aircraft braking action and friction measuring device readings on compacted snow and ice covered runways. The results of their efforts are shown in Figure 14.

Runway Surface Conditions: Compacted Snow and Ice

| VERBAL BRAKING ACTION | GROUND VEHICLE FRICTION READINGS | | | | | | |
|---|---|---|---|---|---|---|---|
| | MU-METER | TAPLEY METER | RUNWAY CONDITION READINGS (RCR) | BOWMONK METER | SAAB FRICTION TESTER | RUNWAY FRICTION TESTER | BV-II SKIDDOMETER |
| EXCELLENT | 0.50 and above | 0.48 and above | 16 and above | 0.46 and above | 0.58 and above | 0.50 and above | 0.58 and above |
| GOOD | 0.49 to 0.36 | 0.46 to 0.35 | 15 to 12 | 0.44 to 0.34 | 0.56 to 0.42 | 0.48 to 0.35 | 0.56 to 0.42 |
| MARGINAL | 0.35 to 0.26 | 0.33 to 0.25 | 11 to 9 | 0.32 to 0.24 | 0.39 to 0.29 | 0.33 to 0.24 | 0.39 to 0.29 |
| POOR | 0.25 and below | 0.24 and below | 8 and below | 0.23 and below | 0.27 and below | 0.23 and below | 0.27 and below |

NOTES:

(1) Mu-meter equipped with smooth RL-2 tires inflated to 10 lb/in.$^2$

(2) Runway friction tester equipped with smooth RL-2 tire inflated to 30 lb/in.$^2$

(3) Saab friction tester and BV-II skiddometer equipped with grooved aero tire inflated to 100 lb/in.$^2$

(4) Ambient air temperature range, -15 to +5° C (5 to 41° F)

(5) Test speed range, 20 to 60 mph except for Tapley meter, RCR, and Bowmonk meter readings which were obtained at speeds from 20 to 40 mph.

Figure 14 Ground Vehicle Friction Reading Correlation Data for Four Levels of Braking Action [13]

For surface conditions other than snow and ice, the FAA says, "Tests on correlation between the friction devices and aircraft were inconclusive and further tests in this area need to be conducted." [8]

2.6.3.2 <u>Friction Measuring Devices v. Surface Texture Measurement Methods.</u> It is an attractive idea to substitute texture measurement for friction measurement "because friction measurements depend on operational conditions, (speed, wetness, temperature, tire characteristics, etc) whereas texture is an intrinsic surface" characteristic [21]. Numerous researchers have attempted to link friction and texture measurement results. Most have found poor correlation and low repeatability [9,10,21,48,49]. One extensive study determined that the best texture measurement could predict friction, as defined by the Mu-Meter, was +/- 13 MuN [10]. Stereophotography [5,10] and noncontact "vision systems" [46] are touted as possible techniques deserving further research. The consensus seems to be that there is a general trend toward higher skid numbers and coefficients of friction with increasing texture depths, but the trend is not definitive enough [10,48,50].

2.7 <u>Frequency of Runway Rubber Removal.</u> The FAA has established friction measurement parameters, based on the Mu-Meter. Example criteria include:

40<MuN<50 for 500 feet and 50<MuN for adjacent 500 feet segments - monitor

MuN<50 for 1000 feet - correct skid deficiency

MuN<40 for 500 feet and MuN<50 for adjacent 500 feet segments - correct skid deficiency

MuN at 40 mph varies more than 10 from the MuN at 60 mph - correct deficiency

MuN>70 for newly grooved or PFC overlaid surfaces - no action [8].

Figure 15 presents a decision flow chart, again based on the Mu-Meter, to help determine when runway rubber removal is beneficial and to assist in evaluating contractor removal operations.

The FAA stated "Airport personnel should make frequent periodic inspections of runway pavement surface conditions" [8], including before and after runway rubber removal attempts [8]. For scheduling purposes and/or when friction measuring devices are unavailable, Figure 16 can be used to estimate when rubber should be removed from high use runways. This graph, first presented by MacLennan, et. al., is included in FAA AC No: 150/5320-12A.

As mentioned earlier in this literature review, "Runways with landings less than 250 million pounds per year rarely have significant rubber accumulation" [12].

Mu A = Mean Friction Level of Rubber Section Before Removal

Mu B = Mean Friction Level of Rubber Section After Removal

Mu C = Mean Friction Level of Control Section (clean pavement edge)

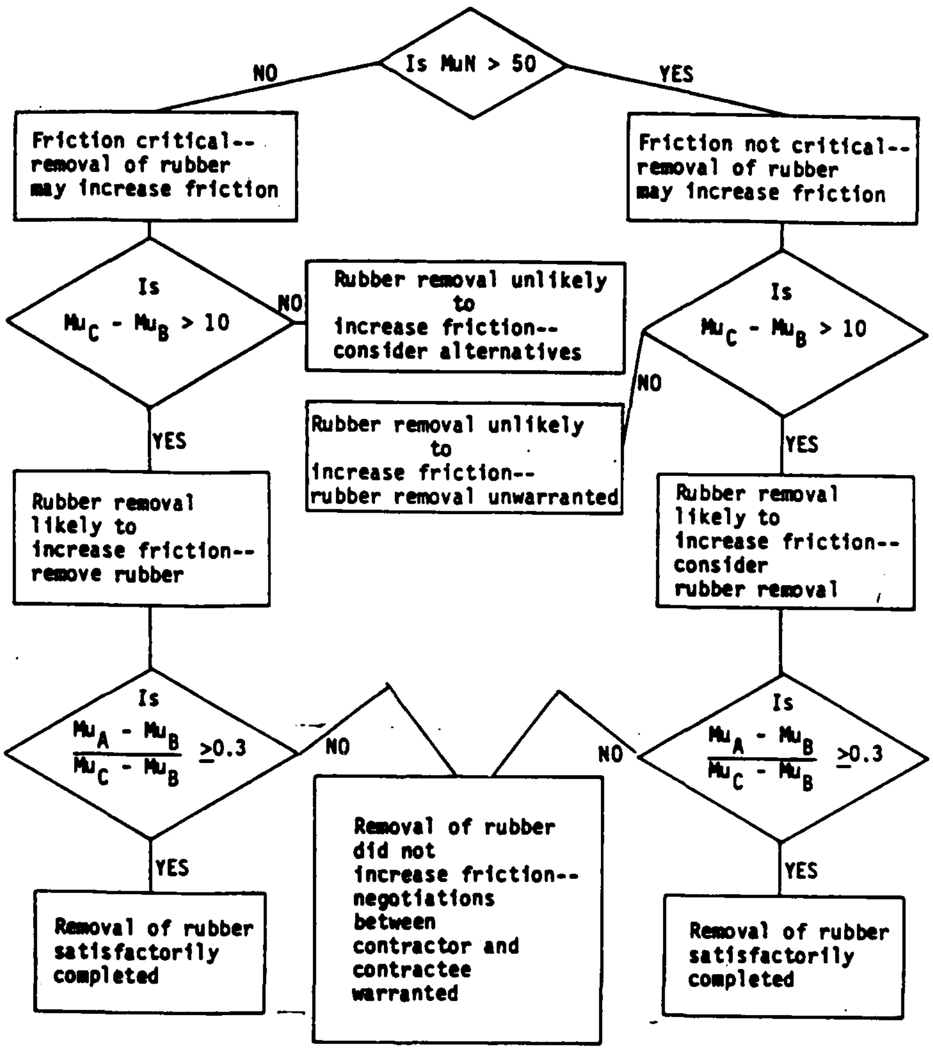



Figure 15 Rubber Removal Flow Chart [10]

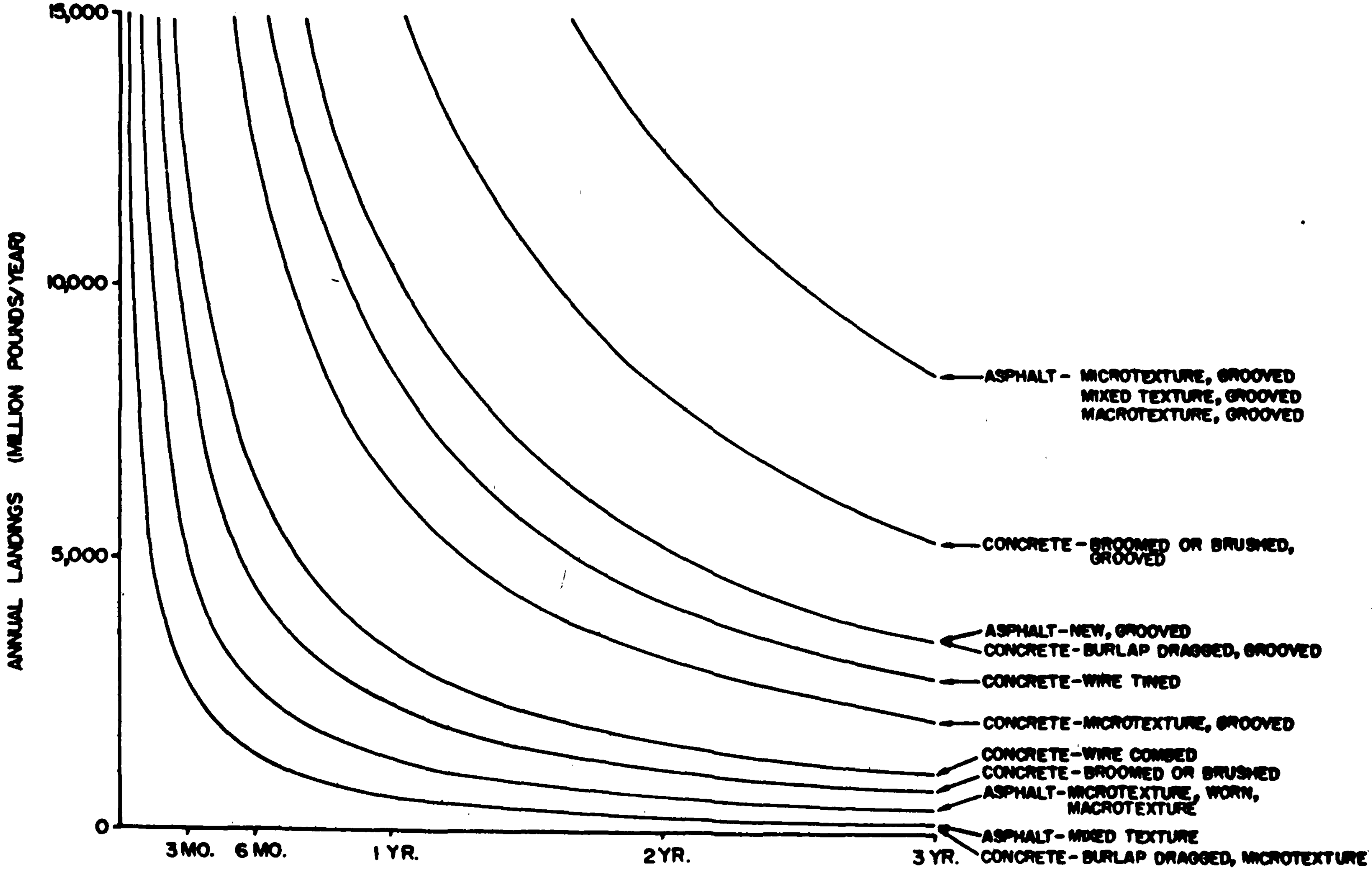



Figure 16 Rubber Removal Frequency for Various Pavement Types [8,12]

2.8 Runway Rubber Removal Methods. A number of elements combine to remove or degrade rubber deposits on a runway. "Weathering, sunlight, microbial activity, snow removal activities (plowing, scraping and sanding) and sweeping" [12] all affect rubber deposits. In house or contracted methods of removal encompass high pressure water, low volume/very high pressure water, chemicals, milling, and high velocity impact. All of these procedures have the potential of polishing the pavement surface and shortening joint sealant life. The problem of removing rubber from PFC overlays is also addressed in this section.

2.8.1 High Pressure Water. This method is presently acknowledged as the most effective means of removing rubber accretions from runway pavement surfaces [8]. Water jets with pressures of 5000-8000 psi are aimed at the pavement surface and rubber is blasted off. Removed rubber flows off the runway with the water runoff. This method is relatively economical, environmentally clean, effective, and quick [8].

2.8.2 Low Volume/Very High Pressure Water. This is one of the newer procedures on the market. Water is directed at the pavement surface through small diameter holes, at pressures of 35,000-60,000 psi, depending on the pavement type and condition This method is more expensive than "high pressure water," but is supposedly more effective and offers less chance of damaging the pavement surface or joint sealant.

2.8.3 Chemicals. On PCC runways, chemicals with a "base of cresylic acid and a blend of benzene, with a synthetic detergent for a wetting agent" are recommended [8]. For AC runways, alkaline chemicals are generally used [8]. Chemicals tend to be volatile and toxic; of course they must be approved by the Environmental Protection Agency (EPA). New biodegradable chemicals under development offer promise for the future of this method.

2.8.4 Milling. When rubber accretions are particularly heavy, or the pavement surface texture is poor, milling techniques can be utilized [8,10]. Economy may constrain use of this procedure.

2.8.5 High Velocity Impact. This entails projecting abrasive particles (sand, shot, or the like) at the pavement surface at very high velocities to blast off the rubber [8,10]. Nowadays, this can be a self-contained operation with mobile machines [8].

2.8.6 Removal From PFC Overlays. Removing rubber from PFC overlays is presently a subject of some concern. The FAA says once rubber fills the voids in a PFC overlay, it is impossible to remove by any known method without seriously damaging the PFC structural integrity [8]. With high pressure water and chemical methods, dislodged rubber is borne with the liquid runoff into the PFC drainage matrix where it can settle and choke the PFC drainage capacity. Particles used in the high impact velocity technique can likewise fill voids and inhibit the PFC drainage capacity. This literature review uncovered no solutions to the problem of removing rubber from a rubber-choked PFC overlay. One author noted that high pressure water might be used: if the PFC is in good repair; if it is properly constructed; and if rubber is removed regularly [10].

2.9 Effectiveness of Runway Rubber Removal. One study dealing with the effectiveness of runway rubber removal found "removal of rubber is likely to improve the friction ... only if the current friction ... has declined sufficiently for the possibility of improvement to exist" [10]. The study authors arbitrarily set the performance requirement to be "effective" at a 30 percent increase in friction (based on the original difference between a rubber-coated section and a clean, non rubber-coated section). The study then measured friction levels at various civilian and military airfields before and after contracted rubber removal operations. The unmodified study found that in only 40 percent of the contracts was rubber effectively removed. Of the 60 percent of contracts where rubber removal was not sufficiently effective, forty percent actually decreased the friction level as a result of removal operations [10]. If nothing else, this points out the need for enhanced monitoring of rubber removal contracts and the potential for long term pavement damage.

2.9.1 Contract Monitoring. To verify rubber removal effectiveness, the FAA says a "friction survey should be conducted before and after" runway rubber removal [8]. At the bulk of United States airports, expensive friction measuring devices are unavailable for this use. To include "before and after" testing for these airports would significantly add to the contract cost. As a result, acceptance of adequate rubber removal is still subjectively determined by visual/experience methods [10].

2.9.2 Long Term Pavement Damage. When rubber is allowed to age on the runway, stronger adhesional bonds may form between the rubber and pavement surface materials [10]. This is widely claimed by rubber removal contractors. The additional energy required to debond this aged rubber may lead to accelerated pavement wear/polishing and increased maintenance costs due to shorter joint sealant life [10]. At the opposite end of the spectrum is removing rubber accretions too frequently. Frequent removal may also lead to accelerated pavement wear/polishing and increased maintenance costs due to shorter joint sealant life. High pressure water may etch a pavement surface, thereby satisfying a contract's friction requirements at the expense of pavement life. High velocity impact methods yield similar conclusions. Even chemicals, if used in too high a concentration, "may deteriorate the hydrocarbon bonding of both asphalt pavements and joint sealants." [10]

# CHAPTER 3 - METHODOLOGY

3.1 Objective. A frequent airport scenario from an airfield pavement engineer viewpoint is as follows. The airport has older, grooved PCC runways. As rubber deposits build up on the runways, pilots begin to complain about unsafe flying conditions. The operations manager requests that maintenance/engineering schedule a runway rubber removal contract. Given the age/condition of the runways, the apparently small amount of built-up rubber, and the difficulty/expense of arranging a time for rubber removal, maintenance/engineering is not sure rubber removal is warranted. In conjunction with operations, maintenance/engineering tries to determine whether rubber really needs to be removed. Since no equipment is available to measure the friction, the runway is visually examined. Rubber deposits do not appear too severe and the decision is made to delay a removal contract. The pilots continue to complain of endangered safety though, and rubber is removed.

In the above process it is apparent that the three groups of individuals (pilots, operations managers, and maintenance personnel) have very different opinions of the importance and necessity of runway rubber removal. Also apparent is the fact that, in the absence of reliable friction measuring equipment, indecision and conflict will continue to plague the issue of whether or not to remove runway rubber accretions. This research seeks to investigate the many factors affecting need and timing of runway rubber removal.

3.2 Research Methods. The research consists of a literature review and questionnaires to pilots, operations managers, and maintenance superintendents.

3.2.1 Literature Review. The literature review portion of this research investigates current knowledge of the factors affecting need and timing of runway rubber removal. Rubber accretions chiefly affect tire-pavement friction. Therefore, the literature review goes into some depth on the history, mechanics, components, and variables of tire-pavement friction. The literature review then looks more specifically at runway rubber removal. Persons involved, methods of measurement, frequency of removal, methods of removal, and effectiveness of removal are all examined.

Government- and scientific community-sponsored research reports formed the bulk of the literature review, but related periodicals, texts, and Federal Aviation Administration advisory circulars were also consulted. Information was obtained from the University of Washington libraries, Lynnwood city library, Air Force Engineering and Services Center, and the Federal Aviation Administration's northwest regional office.

The literature review revealed voids in the current knowledge of factors affecting the need and timing of runway rubber removal. Items meriting further research include:

Tire-Pavement Friction:

- physical laws of adhesion
- mechanics of rolling tire-pavement friction
- response of crosswind landing gear on slippery runways
- correlation of aircraft to friction measuring devices on rubber deposits
- correlation of aircraft and/or friction measuring devices to surface texture measurement devices

Runway Rubber Removal:

- response of pilots, operations managers, and maintenance superintendents to runway rubber accretion
- how airports identify rubber deposits
- how airports remove rubber deposits
- what are the perceptions of involved personnel on rubber removal contract effectiveness in increasing tire-pavement friction
- would an education plan be worthwhile to improve the awareness of: variables/significance of rubber deposits, response of others to rubber deposits, how other airports deal with rubber accretions?

3.2.2 Questionnaires. In this section, the following are discussed: reasons for choosing to use questionnaires, development of the questionnaires, review of the questionnaires, and dispatch of the questionnaires.

3.2.2.1 Reasons for Questionnaire. Given the limited time, resources, and background of the researcher, neither solutions to tire-pavement questions nor a full-scale analysis of the human reactions and methods of dealing with runway rubber were deemed feasible. To lightly explore factors affecting the need and timing of runway rubber removal, interviewing airport personnel was considered. Due to the above limitations though, interviews would have been restricted to the local area. The researcher felt data obtained only from the local level would be of little national use. A nationwide questionnaire was then considered. It was felt that such a questionnaire would have three benefits. First, it would fill gaps of knowledge left from the literature review (especially in the area of current national practices). Second, it would detect variations in the national response to runway rubber and its removal. And third, by questioning a larger database it could be more reliably determined whether or not the human factor, in the runway rubber removal process, merits any further research. The questionnaire method was selected.

3.2.2.2 <u>Questionnaire Development.</u> Pilot, operations manager, and maintenance superintendent questionnaires were formulated. Each questionnaire is devised to roughly parallel the sequence of events individuals might go through in the runway rubber removal process. Initial questions explore what the individuals consider normal operations. The next series of questions investigate how runway rubber accretion is identified. Questions on how involved parties become concerned follow. Then the actual runway rubber removal operation is questioned. Finally, the time to reappearance of runway rubber is queried. In preparing the questionnaires, Professor Joe Mahoney at the University of Washington provided insight on the need for rubber removal research. Colonel Ed Leete of the U.S. Air Force assisted in the pilot questionnaire development. And Professor Don Janssen at the University of Washington guided and corrected the questionnaire preparation. Copies of the three questionnaires are in Appendices C-E. The pilot, operations manager, and maintenance superintendent questionnaires each contain specific and comparative questions.

3.2.2.2.1 <u>Comparative Questions.</u> The questionnaires contain twelve comparative questions. Seven of the twelve comparative questions, adjusted for terminology, are common to each questionnaire. These deal with the individual perceptions of runway rubber and the bureaucratic process of having the runway rubber removed. By determining what each group of individuals considers important and trivial, specific education plans that will help all three groups can be formulated. For example, a pilot may think that rubber is only removed once a year, when it is actually being removed several times a year. This leads to the conclusion that either rubber is not being removed often enough or that the maintenance superintendents and operations managers need to better publicize their activities. In either case group interrelations are strained when it is incorrectly perceived that a group's efforts/needs are not appreciated. Two of the twelve comparative questions request an evaluation of the other group. For example, the pilots and operations managers are asked their impressions of how maintenance superintendents feel about runway rubber build-up, the pilots and maintenance superintendents are asked their impression of how operations managers feel about runway rubber build-up and so forth. These two questions are not designed to create animosity, but rather point out any possible communication breakdowns with the intent of increasing an airport's effectiveness. And three of the twelve questions are common only to the operations managers and maintenance superintendents. These three questions cover sensitivity to runway rubber accretion. If airport personnel find they have been over-, or under-, sensitive to runway rubber, they can adjust their self-inspection checklists accordingly.

3.2.2.2.2 Specific Questions. Specific questions were addressed to all three groups of individuals: pilots, operations managers, and maintenance superintendents.

3.2.2.2.2.1 Pilot Questionnaire. For this research, all pilots were civilian airline pilots representing considerable experience in almost every conceivable situation. The pilot questionnaire consists of nine comparative questions and five specific questions. The comparative questions are discussed above. Pilots are the primary runway users. Because the researcher has no piloting skills, the pilot questionnaire has specific questions designed with a two-fold purpose: first, to give the researcher an idea of what the runway user (a pilot) experiences when landing an aircraft; and second, to explore a pilot's reactions to runway rubber.

3.2.2.2.2.2 Operations Manager Questionnaire. Operations managers are referred to by various names at different airports - for example: operations manager, director of operations, and chief of operations. The operations manager questionnaire contains twelve comparative questions and two specific questions. The comparative questions are discussed above. Airport operations managers have many diversified responsibilities. One of these responsibilities is monitoring runway rubber accretion. The operations manager questionnaire specific questions inquires about the amount of runway rubber accretion as a function of the type and number of landing operations.

3.2.2.2.2.3 Maintenance Superintendent Questionnaire. Maintenance superintendents are also referred to by different titles at different airports - for example: maintenance superintendent, director of maintenance, and airfield engineer. The maintenance superintendent questionnaire asks twelve comparative questions and five specific questions. The comparative questions are discussed above. Maintenance superintendents are acutely aware of airport pavement conditions. Of the five maintenance superintendent specific questions, two are for a general understanding of the types of runways utilized by major United States airports, two are to fill in gaps of knowledge left from the literature review, and one is to determine if runway rubber accretion is even a problem.

3.2.2.3 Questionnaire Review. Review of the questionnaires was performed before dispatch. An airline pilot, an operations manager, and a maintenance superintendent all reviewed their respective questionnaires in an interview with the researcher. The interviews provided insight into the interrelationship of these three groups of individuals. Some questions were eliminated and terminology was changed to reflect current usage.

The operations manager and field maintenance superintendent at a nearby major airport were contacted by telephone and interview dates established. On separate occasions the researcher personally interviewed both individuals. The pilot was contacted through the Air Line Pilot Association. A sample pilot questionnaire was sent to the pilot. After reviewing the form, he made his comments and suggested corrections to the researcher in an extended telephone conversation. All three individuals were very helpful and encouraging on the need for such research.

3.2.2.4 Questionnaire Dispatch. Major United States airport addresses were obtained from the Federal Aviation Administration's northwest regional office. A questionnaire was then sent to the operations manager and maintenance superintendent at thirty-one major United States airports and one smaller state airport (see Figure 17). Appendix A contains a list of all airports contacted to complete questionnaires. The responses of the interviewed airport personnel are included with those of the questionnaire respondents in Chapter 4.

Airline pilots are exposed to many national airports and share common flying experiences, therefore less variation in their response to runway rubber was expected. The interview with the airline pilot, during questionnaire review, provided answers nearly identical to those of Colonel Ed Leete. This further supported the assumption of less variations in response to runway rubber. As a result of this assumption and the difficulty of contacting pilots, only ten pilot questionnaires were prepared. The pilot questionnaires were distributed through the local Air Line Pilot Association chapter.

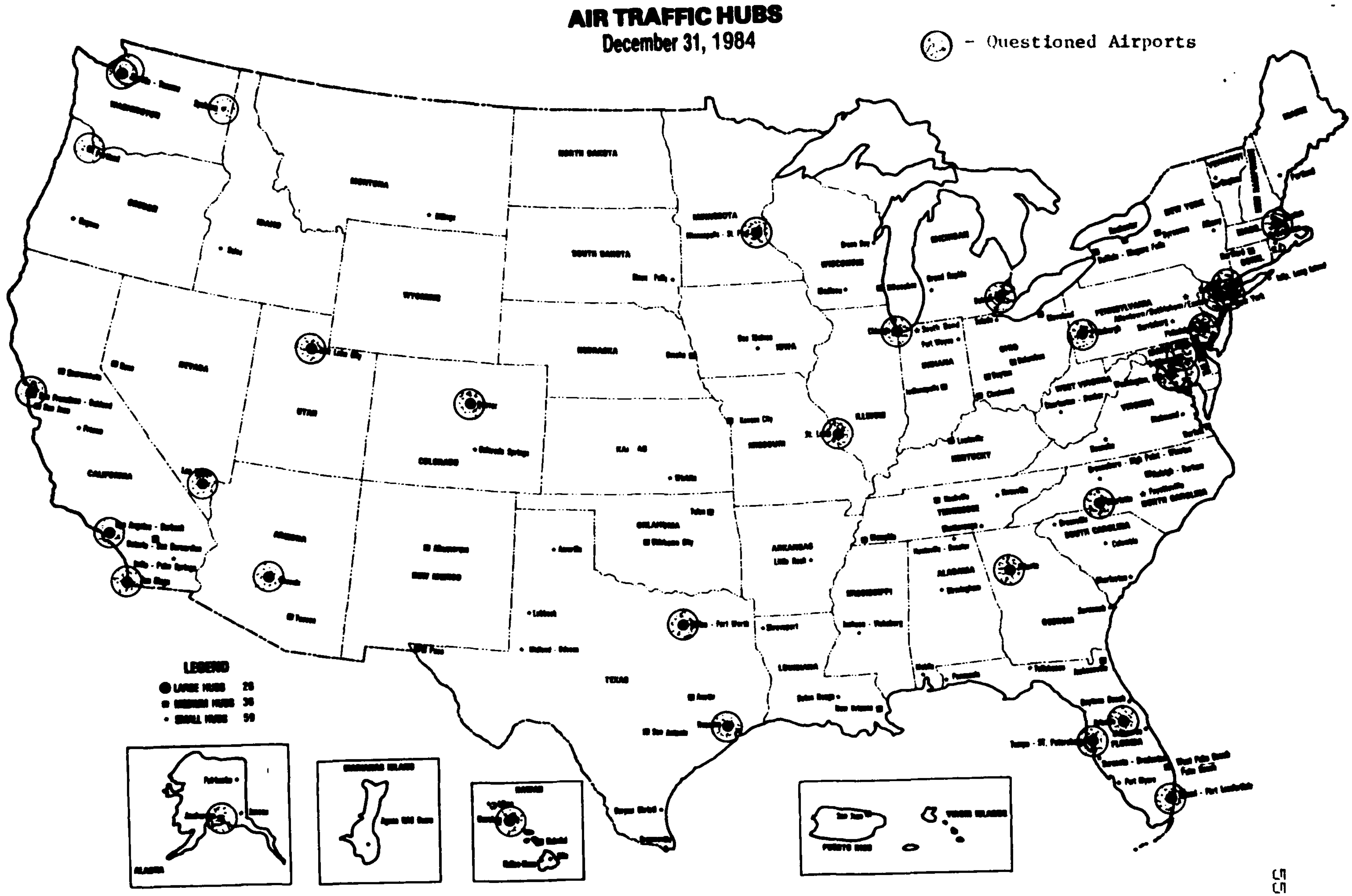



Figure 17 Questioned Airports [51]

# CHAPTER 4 - RESULTS

4.1 Introduction. The results of the research questionnaires are presented in tabular format. Individual and airport names are not used to insure the anonymity of responders. Although certain common friction measuring devices are identified by brand name, this should not be construed as an endorsement of any company's product.

Of the ten pilot questionnaires delivered to the Air Line Pilot Association, all were completed and returned. Of the thirty-three operations managers queried, nineteen responded (57.6%). Of the thirty-three maintenance superintendents questioned, thirteen replied (39.4%). The responding operations managers and maintenance superintendents represented twenty-five of the thirty-three airports surveyed (75.8%). Figure 18 identifies the responding airports; Appendix B lists the responding airports. The responses from the smaller airport were enlightening and similar to the larger airports in many ways. However, due to the disparity in volume of aircraft traffic supported, the researcher felt it best to exclude the smaller airport responses from the tabulated results.

In some instances, responders provided more than one answer and at other times questions were left unanswered. As a result, the total number of responses tabulated rarely matches the number of responders. In the tables, the

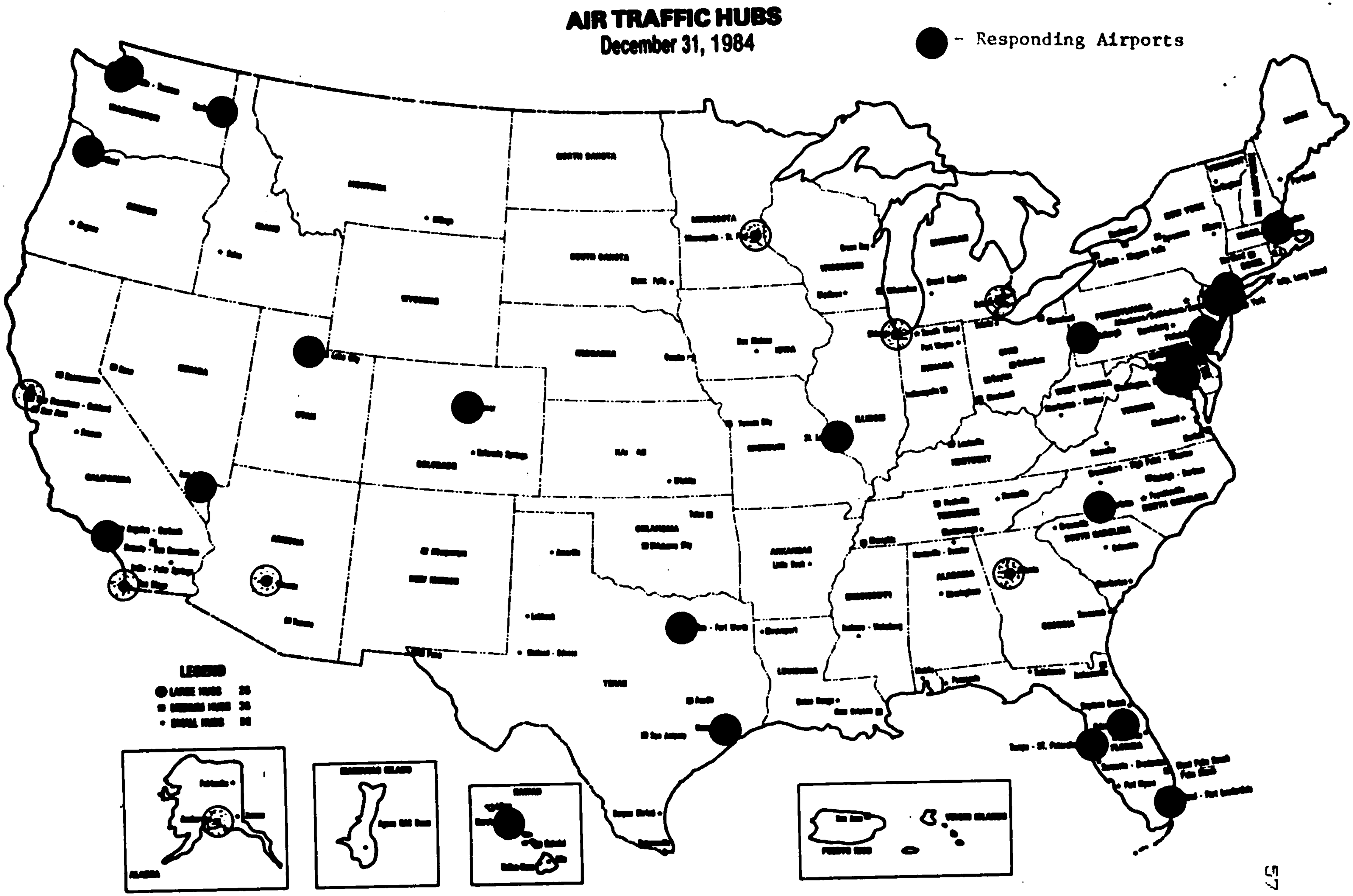



Figure 18 Responding Airports [51]

percentage value in parentheses refers to the percentage of responders giving a certain answer.

The order of analysis parallels a hypothetical sequence of events an airport might go through in removing runway rubber accretions:

- normal airport operations
- runway rubber accretions identified
- involved parties become concerned
- runway rubber accretions removed
- runway rubber removal effectiveness

4.2 Normal Airport Operations. Operations managers, maintenance superintendents, and pilots all provided background information on normal airport operations.

4.2.1 Operations Managers. Operations managers were asked, "What types of aircraft operate at your airport?" All responders indicated that all types of aircraft (from general aviation to the largest air carriers) utilized their airport. Operations managers were then asked, "What is/are the average daily number of aircraft landing operations on your runway(s)?" Answers ranged from 400-900 per day.

4.2.2 Maintenance Superintendents. Maintenance superintendents when asked, "What type of touchdown surface does your airfield have?" responded as shown in Table 1.

Table 1.

Question: What type of touchdown surface does your airfield have?

| Response | Maintenance |
| --- | --- |
| Portland Cement Concrete | 6 |
| Asphalt Concrete | 7 |
| Porous Friction Course | 1 |

When asked, "Is the runway touchdown area grooved?" eleven of twelve responses (92%) were affirmative.

4.2.3 Pilots. The questioned pilots all worked for commercial air lines. The types of aircraft responders fly and their average touchdown speed are shown in Table 2.

Table 2.

Question: What type of aircraft do you fly? What is your speed at touchdown?

| Response | Pilots |
| --- | --- |
| B-727 (131 knots) | 4 |
| B-737 (130 knots) | 1 |
| B-747 (145 knots) | 5 |
| A-300 (140 knots) | 1 |
| MD-80 (128 knots) | 1 |

4.2.4 Assimilation. The typical responding airport has grooved asphalt and/or concrete runway(s). The airport supports 650 landing operations per day with all types of aircraft. Commercial airline pilots, flying predominantly B-727s and B-747s, touchdown at 136 knots.

4.3 Runway Rubber Accretions Identified. Runway rubber accretions can, theoretically, be identified by pilots or airport personnel.

4.3.1 Pilots. Every pilot interviewed or responding to a questionnaire answered affirmatively to the question, "When you are coming in for a landing do you notice rubber deposits in your touchdown area?" Table 3 shows the pilots' answers to whether or not they try to avoid runway rubber deposits.

Table 3.

Question: Do you try to avoid rubber deposits when you touchdown?

| Response | Pilots |
|---|---|
| Yes | 1 ( 9%) |
| Not Normally | 2 (18%) |
| No | 8 (73%) |

One pilot who answered "Not normally" and one pilot who answered "No" commented that it is important to land in the first 1000-1500 feet of the runway. One pilot who answered "No" said he lands in the center with groundtrack aligned with the runway. Two other pilots who answered "No" said rubber accretions are not as much a problem on touchdown as they are on the last 3000 feet of the runway. These two pilots pointed out that the far end of the runway is critical when braking due to a high speed abort, a long landing, or a short runway.

Pilots replied to a question on aircraft sensitivity as shown in Table 4.

Table 4.

Question: How sensitive is the aircraft to side movement in rubber deposit areas?

| Response | Pilots |
| --- | --- |
| Very sensitive on wet runway with crosswind | 3 (27%) |
| Not much | 6 (55%) |
| Other | 2 (18%) |

One of the three pilots who said the aircraft is "Very sensitive..." noted that the aircraft is sensitive to side movement when starting the take-off roll. One pilot apparently read "touchdown area" into the question, because he answered that side movement in rubber deposit areas was not a factor during touchdown. One pilot whose answer was lumped in the "other" category said side movement in rubber deposit areas is a function of air speed, mu, and possibly differential thrust or thrust reverse. The other pilot response included in the "other" category simply stated that rubber areas are extremely slick.

4.3.2 Maintenance Superintendents. When asked whether or not rubber build-up was even a problem at their airfield, maintenance superintendents responded as shown in Table 5.

Table 5.

Question: Is runway rubber build-up a problem at your airfield?

| Response | Maintenance |
|---|---|
| Yes | 3 (33.3%) |
| Potential Problem | 7 (58.3%) |
| No | 1 ( 8.3%) |

Answers included in the "Potential problem" category included comments like: "Only if you do not keep it under control"; "it is becoming a problem with increasing operations"; and "if the build-up is allowed to decrease the friction coefficient."

4.3.3 <u>Comparative Questions.</u> Maintenance superintendents and operations managers were asked if they attempted to measure the runway's skid resistance/braking action. Personnel representing twenty-four airports replied as shown in Table 6.

Table 6.

Question: Do you attempt to measure the runway's skid resistance/braking action? If so, how?

| Response | Airports |
|---|---|
| Yes | 18 (75%) |
| Vehicle | (6) |
| SAAB | (4) |
| Mu-meter | (3) |
| KJ Law Friction Tester | (3) |
| Talk with Pilots | (2) |
| Skiddometer | (1) |
| Tapley Braking Action | (2) |
| No | 5 (21%) |

One airport (4%), not represented above, simply responded that the FAA checks their runway. Four airports reported more than one method of measuring friction. At least two airports had more than one potential method of measuring friction but chose to only specify one method in their response.

Maintenance superintendents, operations managers, and pilots were all asked if rubber deposits are greater or less during any particular season. Table 7 shows their responses.

Table 7.

Question: Are rubber deposits greater or less during any particular season? If so, which?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Yes | 7 (58%) | 9 (50%) | 4 (40%) |
| Greater in summer | (6) | (8) | (4) |
| Greater in fall | (0) | (0) | (0) |
| Greater in winter | (0) | (0) | (0) |
| Greater in spring | (0) | (1) | (0) |
| No | 5 (42%) | 9 (50%) | 6 (60%) |

One maintenance superintendent responded "Yes" without designating any particular season. One maintenance superintendent, one operations manager, and one pilot attributed the increased rubber deposits in summer to higher air and pavement temperatures. One maintenance superintendent, three operati[illegible] managers, and two pilots said rubber deposits were a fu[illegible]tion of traffic; that is, increased traffic leads to more rubber accretion.

4.3.4 Assimilation. Typically, a pilot will notice runway rubber accretions as he comes in for a landing. Upon landing he will not try to avoid rubber deposits. His aircraft will not be sensitive to side movement in rubber deposit areas unless the runway is wet and there is a crosswind. The two pilots who answered "Not normally" when asked if they try to avoid rubber deposits when they touchdown (Table 3) said "Very sensitive on wet runway with crosswind" when asked if their aircraft is sensitive to side movement in rubber deposit areas (Table 4). The pilot who said "Yes" when asked if he tries to avoid rubber deposits when he touches down (Table 3) said "Not much" when asked if his aircraft is sensitive to side movement in rubber deposit areas (Table 4). Maintenance superintendents feel rubber deposits can be a problem if allowed to build.

Airports will during the course of the year attempt to measure runway braking action. Two airports said they only perform measurements in the winter. All five airports that responded "No" in Table 6 are in warm, southern locations.

The general impression as to whether rubber deposits are greater or less in any season is split. Of those airports responding "Yes, greater in summer" in Table 7, 92% were in locations regularly subject to winter snowstorms.

4.4 Involved Parties Become Concerned. All three groups of individuals were asked questions to determine: if runway rubber accretion caused them any anxiety/special concern;

what impression they had of the other individuals' concern for runway rubber accretion; and who, if anybody, they talked to about runway rubber accretion.

4.4.1 Anxiety/Special Concern. When queried as to whether rubber on the runway caused any anxiety/special concern, maintenance superintendents, operations managers, and pilots responded as shown in Table 8.

Table 8.

Question: Does the presence of rubber on the runway cause you any anxiety/concern?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Yes | 4 (33%) | 7 (41%) | 4 (36%) |
| Somewhat | 3 (25%) | 7 (41%) | 6 (55%) |
| No | 5 (42%) | 3 (18%) | 1 ( 9%) |

For maintenance superintendents and operations managers "Somewhat" was defined by, "No, as long as the rubber is removed as needed", or, "Yes, if the rubber is not removed as needed." For pilots "Somewhat" was defined by, "No, on dry runways, but yes on wet, short, dark, narrow, and/or windy runways." Four of the six pilot "Somewhat" answers included a comment alluding to the non-touchdown end of the runway (versus the touchdown area) being critical in foul landing conditions.

4.4.2 Impression of Others' Concern. Replies to these questions varied greatly. The researcher attempted to group similar comments under single headings.

4.4.2.1 Pilots and Operations Managers on Maintenance Superintendents. The impressions pilots and operations managers expressed, on the maintenance superintendents' concern for runway rubber build-up, are compiled in Table 9.

Table 9.

Question: What is your impression of how airfield maintenance superintendents feel about runway rubber build-up?

| Response | Operations | Pilots |
|---|---|---|
| Concerned/Aware | 10 (55.6%) | 1 ( 9%) |
| Regard as Part of Their Job | 3 (16.7%) | 0 |
| Reluctant to Deal With | 1 ( 5.6%) | 2 (18%) |
| Unknown | 4 (22.2%) | 6 (55%) |
| Decisions Based on Economics | 0 | 2 (18%) |

4.4.2.2 Pilots and Maintenance Superintendents on Operations Managers. The impressions pilots and maintenance superintendents expressed, on operations managers' concern for runway rubber build-up, are compiled in Table 10.

Table 10

Question: What is your impression of how operation managers feel about runway rubber build-up?

| Response | Maintenance | Pilots |
|---|---|---|
| Concerned | 10 (83%) | 1 ( 9.0%) |
| Not Much Concern | 0 | 5 (45.5%) |
| Unknown/No Comment/No Experience | 2 (17%) | 5 (45.5%) |

4.4.2.3 Maintenance Superintendents and Operations Managers on Pilots. The impressions maintenance superintendents and operations managers expressed, on pilots' concern for runway rubber build-up, are compiled in Table 11.

Table 11.

Question: What is your impression of how pilots feel about runway rubber build-up?

| Response | Maintenance | Operations |
|---|---|---|
| Concerned | 9 (75%) | 8 (44%) |
| No Feedback/Unknown | 3 (25%) | 10 (56%) |

4.4.3 Intercommunication. This question asked the three groups whom they talked to about removing runway rubber deposits. Different airports handle runway rubber monitoring and contracting in different ways. At two airports represented by returned questionnaires, operations management completely handled runway rubber monitoring and contracting. At one airport maintenance was responsible for runway rubber monitoring and removal - whether by in-house or contract forces. Table 12 contains the responses to this question.

Table 12.

Question: Do you talk to anyone about removing the rubber deposits? If so, whom?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Yes | 11 (92%) | 13 (72%) | 5 (42%) |
| Yes, FAA | (1) | (0) | (1) |
| Yes, Port Authority | (0) | (1) | (1) |
| Yes, Operations | (2) | (0) | (3) |
| Yes, Other Airports | (0) | (4) | (0) |
| Yes, Maintenance | (4) | (5) | (0) |
| Yes, Consultant | (1) | (0) | (0) |
| Yes, Vendors | (1) | (0) | (0) |
| Yes, Contractor | (5) | (5) | (0) |
| Yes, Pilots | (1) | (0) | (0) |
| Yes, A.L.P.A. Safety | (0) | (0) | (1) |
| No | 1 ( 8%) | 5 (28%) | 7 (58%) |

Six maintenance superintendents, four operations managers, and two pilots said they talked to more than one individual/organization about runway rubber removal.

Replies from both operations and maintenance at five airports were received. Of these five, two operations managers listed maintenance as someone they talked to about runway rubber removal, but maintenance said they only talked to contractors. At one of these six airports, both operations and maintenance said they only talked to the port authority; at another airport both said they only talked to the contractor. At the last of these five airports, maintenance said they talked to operations, but operations said they did not talk to maintenance.

4.4.4 <u>Assimilation.</u> Pilots and operations managers are especially concerned about runway rubber accretion. In Table 20, pilots emphasize their concern in foul landing conditions. Maintenance superintendents are aware of rubber accretion (Table 5) but are not overly concerned (Table 8). Operations managers and maintenance superintendents have an accurate impression of how each other feels about runway rubber (Table 8 v. Tables 9 and 10). Pilots do not know what maintenance people feel about runway rubber (Table 9). Nor do pilots know how operations managers feel about runway rubber, though they have a suspicion that operations managers do not care very much (Table 10). Maintenance superintendents have an accurate impression of how pilots feel about rubber accretions (Table 11). Operations managers do not know how pilots feel about rubber accretions, since they receive no feedback (Table 11).

Maintenance superintendents and operations managers talk to others about removing rubber deposits more than pilots. Of the pilots who do talk to others, 60% talk to operations managers. Note: no operations managers say they talk to pilots (Table 12). Of the pilots, 91% say they are at least somewhat concerned about rubber accretions (Table 8), but in Table 12, 59% of pilots never talk to others about removing the deposits.

4.5 Runway Rubber Accretions Removed. This series of questions investigates the perceived frequency, method, cost, and effectiveness of runway rubber removal.

4.5.1 Removal Frequency. The maintenance superintendents, operations managers, and pilots were all asked how often runway rubber was removed; their responses are shown in Table 13.

One airport removes rubber every year or as required (counted as 1 x/year). Another airport removes rubber four times a year or as required (counted as 4 x/year). Replies from both operations and maintenance were received from five airports. At four of the five airports, both agreed on the runway rubber removal frequency. At one of these five airports, maintenance said, "Every other year or as required", while operations only said, "As required" (counted as < 1x/year).

Table 13.

Question: How often is rubber removed?

| Response | Airports | Pilots |
|---|---|---|
| < 1x/year | 6 (25%) | 0 |
| 1x/year | 2 ( 8%) | 2 (18%) |
| 2x/year | 7 (29%) | 0 |
| 3x/year | 4 (17%) | 0 |
| 4x/year | 2 ( 8%) | 0 |
| => 5X/year | 3 (13%) | 0 |
| No Apparent Schedule | 0 | 2 (18%) |
| Unknown | 0 | 7 (64%) |

4.5.2 Removal Method. The maintenance superintendents were asked which method of runway rubber removal was used at their airport and why. They responded as shown in Table 14.

One respondent, who uses high pressure water on PCC and a combination of chemical/high pressure water on asphalt, said cost is a factor. One maintenance superintendent said he has found some minor damage to the pavement surfaces and believes it is a result of the high pressure water technique. As a result, he is trying to use high pressure water less and detergent/scrubbing more (counted as chemical in Table 14). Two individuals said they have always used high pressure water and never looked into another method. In addition to the two airports already using low volume/high pressure water, one maintenance superintendent and one operations manager (even though he was not asked the question) said they are now looking into the use of low volume/high pressure water. Both seemed enthused about the potential of this new method. Another respondent, who utilizes both chemical and high pressure water techniques, said he uses the chemicals on surface build-up and the high pressure water on rubber in the grooves. One maintenance superintendent said high pressure water is cheap and effective.

Table 14.

Question: How do you remove rubber? Why this method?

| Response | Maintenance |
|---|---|
| High Pressure Water | 9 |
| Chemicals | 3 |
| Low volume/high pressure water | 2 |

4.5.3 Removal Cost. The maintenance superintendents were also queried on the cost of runway rubber removal; the responses are shown in Table 15.

Reported costs for high pressure water ranged from $0.015/SF to $0.12/SF. One respondent said a combination of chemicals and high pressure water for asphalt costs $0.05/SF. Another maintenance superintendent who utilizes chemicals in-house said the costs are hard to pin down. One of the airports using low volume/high pressure water said it costs $0.035/SF; the other said it costs $0.10/SF. The maintenance superintendents were not asked how many square feet of pavement they typically include in their rubber removal contracts.

Table 15.

Question: How much does rubber removal cost?

| Response | Maintenance |
|---|---|
| $0.01-0.019/SF | 1 ( 8%) |
| $0.02-0.029/SF | 2 (25%) |
| $0.03-0.039/SF | 2 ( 8%) |
| $0.04-0.049/SF | 2 (17%) |
| $0.10-0.12/SF | 2 (17%) |
| $30,000/Year | 1 ( 8%) |
| $276,000-340,000/Year | 1 ( 8%) |
| Did not know | 1 ( 8%) |

4.5.4 Assimilation. Given the similarity of pavement surfaces and air traffic at responding airports, the variety of responses to "How often is rubber removed?" (Table 13) is surprising. There is no apparent geographical or climatological trend. Pilots generally do not know how often rubber is removed (Table 13). When rubber is removed it is usually done by high pressure water (Table 14). When asked if they had any further comments (Table 20) maintenance superintendents indicated an interest in newer removal techniques. As with frequency of removal, there is a wide scatter in the cost of removal.

4.6 Runway Rubber Removal Effectiveness. This series of questions investigated the expectations and perceived effectiveness of runway rubber removal. Airport personnel were further questioned on how they thought pilots felt after runway rubber had been removed. The sensitivity to reappearance of runway rubber accretions was also explored.

4.6.1 Expectations. Maintenance superintendents, operations managers, and pilots were all asked how they expected the runway to change after rubber removal. They responded as shown in Table 16.

Two maintenance superintendents and three operations managers gave multiple answers. One operations manager, whose answer is not included in Table 16, simply said they expect less built-up rubber after removal. One pilot, whose answer is not included in Table 16, said he expects better wheel spinup for auto speedbrake and anti-skid operation. One operations manager commented that they expect Saab Friction Tester readings in the upper 0.8's after removal. Another operations manager said they expect KJ Law Runway Friction Tester readings above 0.9 after removal. Four pilots did not respond to the inquiry.

Table 16.

Question: How do you expect the runway to change after rubber is removed?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Improved Skid Resistance/ Braking Action/Friction | 7 | 14 | 7 |
| FAA Acceptable | 1 | 0 | 0 |
| Cleaner/Markings Distinct | 2 | 4 | 0 |
| Improved Drainage | 2 | 0 | 0 |
| No Rubber in Grooves | 2 | 0 | 0 |
| Safer | 1 | 1 | 0 |
| Original Condition | 0 | 0 | 1 |
| Unsure | 0 | 1 | 0 |

4.6.2 Perceived Effectiveness. Maintenance superintendents, operations managers, and pilots were next asked whether or not the runway rubber removal process was effective in increasing aircraft skid resistance/braking action. The responses are shown in Table 17.

One maintenance superintendent whose response was categorized "Unknown" said he uses a vehicle, not an aircraft, to measure the effectiveness of runway rubber removal. Another maintenance superintendent pointed out that runway rubber removal is only effective to a point. Then, he commented, the grooves round and the surface polishes. Two operations managers and three pilots gave emphatic "Yes" responses.

Table 17.

Question: Is the rubber removal process effective in increasing aircraft skid resistance/braking action?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Yes | 9 (75%) | 13 (72.2%) | 7 (64%) |
| Probably/Believe So | 0 | 3 (16.7%) | 3 (27%) |
| No | 0 | 1 ( 5.6%) | 0 |
| Unknown | 3 (25%) | 1 ( 5.6%) | 1 ( 9%) |

4.6.3 Perceived Pilot Response. The maintenance superintendents and operations managers were also asked whether or not they got the impression that pilots felt any different after runway rubber removal. They responded as shown in Table 18.

One maintenance superintendent, whose answer was counted as a "No", said pilots are very concerned about runway rubber accretions, but the majority cannot make the distinction between visual results and the actual friction coefficient after rubber removal. Two operations managers' answers counted as "Unknown" could have been construed differently. One of the two said, "Hope so" while the other said, "Not a great change." One operations manager, whose reply is not included, said "Rubber has never been removed."

Table 18.

Question: Do you get the impression that pilots feel any different after rubber has been removed?

| Response | Maintenance | Operations |
|---|---|---|
| Yes | 4 (33.3%) | 3 (17.6%) |
| Unknown | 7 (58.3%) | 11 (64.7%) |
| No | 1 ( 8.3%) | 3 (17.6%) |

4.6.4 Runway Rubber Accretions Reappear. Maintenance superintendents and operations managers were asked how long it took before they again noticed rubber deposits in the runway touchdown area. Their responses are shown in Table 19.

Table 19.

Question: Approximately how long does it take after rubber removal before you again notice rubber deposits in the touchdown area?

| Response | Maintenance | Operations |
|---|---|---|
| Immediately | 5 (41.7%) | 5 (33%) |
| 0-1 month | 3 (25.0%) | 5 (33%) |
| 1-3 month | 2 (16.7%) | 4 (27%) |
| 3-6 month | 1 ( 8.3%) | 1 ( 7%) |
| > 6 month | 1 ( 8.3%) | 0 |

The operations manager who reported never having removed rubber replied "Unsure". His answer is not reflected in Table 19.

4.6.5 Assimilation. Maintenance superintendents, operations managers, and pilots all expect, and perceive, that tire-pavement friction increases after rubber removal (Tables 16 and 17). Operations managers are sensitive to a need for clean, distinct pavement markings (Table 16). Maintenance superintendents are sensitive to the need for clean grooves and improved drainage (Table 16). Of the pilots, 82% say they do not know when rubber is removed (Table 13), yet 91% of pilots say they think rubber removal is effective (Table 17). Maintenance superintendents and operations managers typically do not know how pilots feel after rubber removal (Table 18). Seven respondents to the question of how pilots feel after rubber has been removed (Table 18) have the impression that pilots do feel different after rubber removal; however, only one individual says he talks to pilots (Table 12). Airport personnel are alert to the reappearance of rubber accretions (Table 19). There is a slight trend toward personnel at airports in warmer climates more quickly identifying rubber reappearance.

4.7 Other Thoughts/Comments. Finally, maintenance superintendents (M), operations managers (O), and pilots (P) were asked if they had any other thoughts or comments on runway rubber accretion and removal. The various responses are summarized in Table 20.

Table 20.

Question: Do you have any other thoughts or comments on runway rubber accretion/build-up and removal?

| Response | Maintenance | Operations | Pilots |
|---|---|---|---|
| Safety is Important | 0 | 1 | 2 |
| Inevitable,Removal Necessary | 1 | 2 | 0 |
| New Technology Looks Good | 3 | 1 | 0 |
| Makes Markings More Distinct | 0 | 2 | 0 |
| Can be Critical in Foul Landing Conditions | 0 | 0 | 4 |
| Need More Research | 1 | 0 | 1 |
| Miscellaneous | 2 | 6 | 1 |
| No Comments | 5 | 6 | 3 |

Of those who said "New technology looks good", two were referring to non-hazardous/biodegradable chemicals and two were referring to low pressure/high volume water removal methods. In their "Can be critical in foul conditions" comments, the pilots said rubber deposits are more of a concern on short, dark, wet, narrow, and/or windy runways. They added that the far end of the runway is more critical than the touchdown area, because this is where the brakes are applied on aborted takeoffs, short runways, or roll outs. The miscellaneous comments are listed as follows:

- high pressure water removes rubber better than chemicals (O)
- grooved runways fare better even with rubber build-up (P)
- expect efficient removal yet minimal pavement damage (O)
- increased wide body air traffic, increased landing weights, and increased landing speeds mean runway rubber will have to be removed more frequently in the future (O)
- determining effective rubber removal procedures which do not harm the environment or damage the runway surface is a major challenge facing airport operators (O)
- runway rubber removal sucks because you have to work from midnight to 6 AM and then still work your regular job (M)
- in a pilot's mind it is psychological - we have never received any comments from anyone except the FAA after rubber has been removed (M)
- concrete is easier to clean and maintain (O)
- with all runways having a porous friction surface, we have been reluctant to remove rubber (O).

4.8 <u>Interest in Research</u>. Of the thirteen responding maintenance superintendents, twelve (92%) requested summaries of the research results. Of the nineteen responding operations managers, sixteen (84%) requested summaries. And, of the eleven responding pilots, two (18%) requested personal copies of the summary and four (36%) requested copies for various offices within ALPA. The ALPA field office secretary also requested a summary.

# CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 General. This research has investigated the many factors affecting the need and timing of rubber removal. The literature review portion delved into the history, mechanics, components, and factors bearing on tire-pavement friction. Then, runway rubber removal was examined, including: persons involved, methods of measurement, frequency of removal, methods of removal, and effectiveness of removal. Questionnaires were prepared next and given to individuals involved in the problem of runway rubber and its removal - that is, pilots, operations managers, and maintenance superintendents. The questionnaires explored normal airport operations, how runway rubber accretions are identified, how involved parties become concerned, how runway rubber is removed, and how effective rubber removal operations are.

5.2 Conclusions. In the process of investigating runway rubber removal, areas of tire-pavement friction that merited further investigation were identified. These are listed but not considered further in this research. Conclusions on runway rubber removal are grouped into the subheadings: tire-pavement friction, regional variations, decision to remove rubber, variation in cost, communication, design considerations, contractor operations, and education.

5.2.1 Tire-Pavement Friction. Items meriting further research include:

- physical laws of adhesion
- mechanics of rolling tire-pavement friction
- response of crosswind landing gear on slippery runways
- correlation of aircraft braking action to friction measuring device readings on rubber deposits
- correlation of aircraft and/or friction measuring devices to surface texture measurement methods

5.2.2 Regional Variations. Regional variations are limited. Only two distinct variations in the response to runway rubber removal are noticeable. These are in the areas of friction measurement (Table 6) and perceived effects of seasonal changes in the amount of rubber deposited (Table 7). Otherwise, there is no identifiable regional trend in personnel reaction to rubber (Tables 5 and 8), communication (Table 12), removal frequency (Table 13), method of removal (Table 14), or removal cost (Table 15).

5.2.2.1 Variations. Of the 5 airports who responded that they do not attempt to measure runway braking action, 100% were in warm, southern areas. These airports removed rubber no less or more frequently than the other airports (Table 13). Apparently their visual rubber removal identification procedures yield the same results as expensive friction measuring devices.

Of those who perceived a seasonal difference in the amount of rubber deposition, 93% said rubber accretion was greater in the summer. In comments, this seasonal variation was attributed to higher air/pavement temperatures and increased landing operations. Of the airports saying "Yes, greater in summer," 92% were in areas with extreme seasonal differences. Apparently airports in more moderate climates do not have enough variation in the amount of rubber deposited to notice any difference. As responders commented, higher summer air/pavement temperatures and increased landing operations play a role in rubber deposition. Rubber is still deposited in the winter however. Airports with four distinct seasons inadvertently remove rubber in the winter with snow plows and de-icing chemicals (another reason for the seemingly seasonal difference).

5.2.2.2 Non-Variations. Non-variation in personnel reaction to rubber and communication was expected. As noted in the literature review, most airport personnel attend the same seminars, read the same literature, and are in basically similar organizations (that is, airports have an operations side and a maintenance side).

Non-variation in method of removal was also expected. Again, airport personnel are constantly talking to each other and reading the same literature. The most common method of removal (high pressure water) is accessible to all U.S. airports.

Non-variation in frequency of removal was not anticipated. With higher year-round temperatures, winter tourists, and no snow/ice to deal with, southern airports were expected to remove rubber more frequently. This was not true. The frequency of removal in southern airports matched that of the more seasonal northern airports.

5.2.3 Decision to Remove Rubber. Generally, airport personnel go through a disjointed process in electing to remove rubber accretions. Remembering that all the airports responding are for the most part peers, a quick glance at the replies to "How often is rubber removed?" (Table 13) is disturbing. The responses vary wildly. According to Table 6, most airports put a great deal of effort and expense into determining when rubber should be removed based on available friction. How then can there be such variation in the frequency of removal? Many other factors may weight the decision to remove rubber. For example, type of runway, age/condition of runway, and difficulty/expense of arranging a time for removal all have to be considered.

5.2.4 <u>Variation in Cost.</u> Costs vary widely and inconsistently throughout the U.S. Given that there are only a few companies dedicated to removing runway rubber (normally one man and his truck per region) and that all airports have rubber deposited in nearly the same square footage, rubber removal costs could be expected to be nearly identical. As Table 15 indicates, they were not. Also surprising was the fact that no region had uniformly high or low costs. Consider the variation in contract amount for a 150,000 SF area. At the lowest response ($0.015/SF) this equates to a contract amount of $2,250. At the highest response ($0.11/SF) this equates to a contract amount of $16,500 - a 733% increase over the lower amount. The following reasons for this erratic variation in costs are offered in speculation: inexpensive, dedicated rubber removal contractors contacted on short notice may be unavailable so that more expensive non-dedicated contractors must be utilized; contractors charge differently for different airports; airports may not remove rubber from all their runways at the same time forcing contractors to bid on lower square footage; or paint removal is included in some rubber removal contracts but not others.

5.2.5 <u>Communication.</u> In evaluating the need or effectiveness of runway rubber removal, pilots are outside the communication loop. Operations managers and maintenance superintendents are expected to have regular interaction.

From the accurate understanding of each other's impression about rubber accretion, demonstrated in Table 8 v. Tables 9 and 10, it appears they communicate freely. Maintenance superintendents accurately appraise the impression of pilots, regarding rubber deposits (Table 8 v. Table 11). But pilots do not know how maintenance superintendents or operations managers feel about runway rubber (Table 8 v. Tables 9 and 10). Nor do operations managers know how pilots feel about rubber deposits (Table 8 v. Table 11). When the responses to, "Do you talk to anyone about removing the rubber deposits? If so, whom?" (Table 12) are considered, it is not surprising that there is such poor understanding of one another. Only one individual said they talk to pilots, indicating a need for improved communication on the part of maintenance superintendents and operations managers. Pilots could communicate better as well. From Table 8, 91% of pilots are at least somewhat concerned about rubber accretions - some emphatically so. Yet, in Table 12, 59% of pilots say they talk to no one about removal of rubber.

Once rubber has been removed, maintenance superintendents and operations managers do not get any feedback from pilots on the effectiveness of the removal operation. This is understandable though, given that pilots do not spend their time exclusively at one airport and therefore do not know whether rubber has been removed or not (Table 13).

5.2.6 Design Considerations. Pilot comments reveal that aircraft turns on areas subject to rubber accretion are undesirable. The literature review discloses that grooved runways are effective at increasing tire-pavement friction and PFC overlays are best used where airport landing operations will not exceed 450 per day.

5.2.6.1 Aircraft Turns. Pilot comments (Tables 3 and 20) clearly indicate their concern about rubber deposits on short, dark, wet, narrow, and/or windy runways. On aborted takeoffs, short runways, or roll outs, pilots do not want to have to apply their brakes over slick rubber deposits. Airport designers (runway dimensions allowing) can design airfields so that aircraft are not forced to turn on areas of low tire-pavement friction. If high speed taxiways can be constructed in useful locations, away from rubber deposit areas, the need for runway rubber removal is averted.

5.2.6.2 Grooves/PFC. Grooves are noticeably effective at increasing drainage and tire-pavement friction. One pilot even remarked on how rubber seemed to be less of a problem on grooved runways. The FAA recommends PFC overlays not be used where landing operations may exceed 450 per day. A competent method of removing rubber from PFC overlays is urgently needed at airports today.

5.2.7 Contractor Operations. An airport can ensure adequate runway rubber removal by closely monitoring contractor operations. Specifications can be written that require the contractor to meet a certain percentage increase in tire-pavement friction. At large airports with friction measuring devices, before and after removal checks can be made to verify the required tire-pavement friction increase is met. Smaller airports may consider the expense of renting a friction measuring device to perform the before and after checks. High pressure water equipment is capable of seriously damaging a pavement, so contractor operations should be monitored to verify tire-pavement friction is not being increased at the expense of pavement life.

5.2.8 Education. Periodic instruction on runway rubber accretion would benefit pilots, operations managers, and maintenance superintendents. Due to normal personnel turnover and advancing technology, a periodic education program would help all involved parties keep abreast of the factors affecting the need and timing of rubber removal. Suggested topics follow.

5.2.8.1 Tire-Pavement Friction (including the mechanics, components, and factors - such as contaminants, speed, temperature, seasons, and rubber deposits - bearing on tire-pavement friction). Pilots, operations managers, and maintenance superintendents are generally well-educated, professional people who take pride in their work. Briefly explaining the fundamentals of tire-pavement friction will take away any fear of the unknown they may have. At the same time, instruction may alert others to the potential danger of rubber deposit areas. The need for such schooling can be seen in pilot responses indicated in Tables 3, 4, and 8. Some pilots are extremely sensitive to rubber accretion areas, while others are apparently oblivious of the possible hazard.

5.2.8.2 Communication (including inter- and intra-group communication). If maintenance superintendents, operations managers, and pilots talk with - not at - one another, they will be able to assist one another in meeting their mutual needs. If intra-group communication is good, the frequency of rubber removal might standardize to some degree. Newer, more effective techniques for monitoring and removing rubber can be more rapidly implemented.

5.3 Recommendations. In this section, six recommendations are offered that encompass: research, surface texture measurement methods, scheduling, design, education, and communication.

5.3.1 Research. Research into the following areas should be pursued:

- physical laws of adhesion and affect of rubber deposits on adhesion
- mechanics of rolling tire-pavement friction, with and without rubber deposits
- response of crosswind landing gear on slippery runways
- correlation of aircraft to friction measuring devices on rubber deposits
- correlation of aircraft and/or friction measuring devices to surface texture measurement methods (see below)
- methods of removing rubber deposits from a PFC overlay
- improved methods of removing rubber deposits from AC and PCC surfaces

5.3.2 Surface Texture Measurement Methods. A simple, reliable, inexpensive surface texture measurement method should be developed and made required equipment at airports not possessing a friction measuring device. If such a method were developed and its readings correlated with the friction measuring devices, rubber removal specifications could be written to require a minimum increase in tire-pavement friction from removal operations. Both large and small airports could then effectively monitor contractor rubber removal operations. Also, once a history of frictional variations is established at an airport, rubber removal contracts can be scheduled in advance. Safety and economy could be optimally balanced.

5.3.3 Scheduling. Pavement type and condition permitting, runway rubber removal contracts should be scheduled at the same time for all runways (alternate landings) and at the same time as airfield paint removal operations. As discussed above, a history of when rubber accretions are worst can be created and rubber removal contracts scheduled accordingly. By having contracts for larger square footage of removal scheduled well in advance, bid prices should be lower. Preparation for downtime can proceed more leisurely as well.

5.3.4 Design. At airports with runways of allowable dimensions, high speed taxiways should be constructed just prior to rubber deposit areas. Touchdown areas should also be grooved unless an airport has a PFC overlay. If aircraft can bypass troublesome rubber deposit areas, safety improves and the need for rubber removal contracts is reduced.

5.3.5 Education. Periodic education programs covering factors affecting the need and timing of rubber removal should be implemented. Such instruction will keep all involved parties informed and unified in working toward a common goal.

5.3.6 Communication. Inter- and intra-group communication should be heavily stressed. If inter-group communication is improved, concerns can be addressed. If intra-group communication is improved, the concerns can be solved with the most economical and effective methods. Possible means of accomplishing this include: FAA add inter-group communication to airport inspection checklists (airports would have the autonomy to choose whatever method of inter-group communication promotion they desire; for example computer bulletin boards and/or enforced attendance by key personnel at inter-disciplinary meetings), magazines specific to each group of individuals could print articles by members of the other group, and the ALPA could periodically publish their concerns for the maintenance superintendents and operations managers (realistic stories that take the reader into the cockpit and demonstrate what a pilot goes through in landing his aircraft would be more effective than lectures).

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# APPENDIX - A

## List of Airports Questioned

1. Anchorage International Airport (IAP)
2. Phoenix Sky Harbor IAP
3. Los Angeles IAP
4. Lindbergh Field (San Diego)
5. San Francisco IAP
6. Stapleton (Denver) IAP
7. Dulles IAP
8. Washington National Airport
9. Miami IAP
10. Orlando IAP
11. Tampa IAP
12. Chicago-O'Hare IAP
13. Logan (East Boston) IAP
14. Baltimore-Washington IAP
15. Detroit City Airport
16. Minneapolis-St Paul IAP
17. Lambert/St Louis IAP
18. Charlotte/Douglas IAP
19. Newark IAP
20. McCarran (Las Vegas) IAP
21. John F. Kennedy (Jamaica, NY) IAP
22. La Guardia (Flushing, NY) IAP
23. Portland IAP
24. Hartsfield-Atlanta IAP
25. Honolulu IAP
26. Greater Pittsburgh IAP
27. Philadelphia IAP
28. Dallas/Ft Worth IAP
29. Houston Intercontinental Airport
30. Salt Lake City IAP
31. Boeing Field/King Co. IAP
32. Seattle-Tacoma IAP
33. Spokane IAP

APPENDIX - B

List of Airports Responding

1. Los Angeles IAP
2. Stapleton (Denver) IAP
3. Dulles IAP
4. Washington National Airport
5. Miami IAP
6. Orlando IAP
7. Tampa IAP
8. Logan (East Boston) IAP
9. Baltimore-Washington IAP
10. Lambert/St Louis IAP
11. Charlotte/Douglas IAP
12. Newark IAP
13. McCarran (Las Vegas) IAP
14. John F. Kennedy (Jamaica, NY) IAP
15. La Guardia (Flushing, NY) IAP
16. Portland IAP
17. Honolulu IAP
18. Greater Pittsburgh IAP
19. Philadelphia IAP
20. Dallas/Ft Worth IAP
21. Houston Intercontinental Airport
22. Salt Lake City IAP
23. Boeing Field/King Co. IAP
24. Seattle-Tacoma IAP
25. Spokane IAP

# APPENDIX - C

## Pilot Questionnaire

1. What type of aircraft do you fly?

2. What is your speed at touchdown?

3. When you're coming in for a landing do you notice rubber deposits in your touchdown area?

4. Does the presence of rubber on the runway cause you any special concern?

5. Do you try to avoid rubber deposits when you touchdown?

6. How sensitive is the aircraft to side movement in rubber deposit areas?

7. Are rubber deposits greater or less during any particular season? If so, which?

8. Do you talk to anyone about removing the rubber deposits? If so, whom?

9. What is your impression of how operations managers feel about runway rubber build-up?

10. What is your impression of how airfield maintenance superintendents feel about runway rubber build-up?

11. How often is rubber removed?

12. How do you expect the runway to change after rubber is removed?

13. Is the rubber removal process effective in increasing your aircraft's braking action?

14. Do you have any other thoughts or comments on runway rubber acretion and removal?

15. Would you like a copy of the survey results? If so, please attach a business card.

# APPENDIX - D

## Operations Manager Questionnaire

1. What types of aircraft operate at your airport?

2. What is/are the average daily number of aircraft landing operations on your runway(s)?

3. Do you attempt to measure the runway's braking action? If so, how?

4. Does the presence of rubber on the runway cause you any anxiety?

5. Are rubber deposits greater or less during any particular season? If so, which?

6. Do you talk to anyone about removing the rubber deposits? If so, whom?

7. What is your impression of how pilots feel about runway rubber build-up?

8. What is your impression of how airfield maintenance superintendents feel about runway rubber build-up?

9. How often is rubber removed?

10. How do you expect the runway to change after rubber is removed?

11. Is the rubber removal process effective in increasing aircraft braking action?

12. Do you get the impression that pilots feel any different after rubber has been removed?

13. Approximately how long does it take after rubber removal before you again notice rubber deposits in the touchdown area?

14. Do you have any other thoughts or comments on runway rubber build-up and removal?

15. Would you like a copy of the survey results? If so, please attach a business card.

# APPENDIX - E

## Maintenance Superintendent Questionnaire

1. What type of touchdown surface does your airfield have?

2. Is the runway touchdown area grooved?

3. Is runway rubber build-up a problem at your airfield?

4. Do you attempt to measure the runway's skid resistance? If so, how?

5. Does the presence of rubber on the runway cause you any anxiety?

6. Are rubber deposits greater or less during any particular season? If so, which?

7. Do you talk to anyone about removing the rubber deposits? If so, whom?

8. What is your impression of how pilots feel about runway rubber build-up?

9. What is your impression of how operations managers feel about runway rubber build-up?

10. How often is rubber removed?

11. How do you remove rubber? Why this method?

12. How much does rubber removal cost?

13. How do you expect the runway to change after rubber is removed?

14. Is the rubber removal process effective in increasing aircraft skid resistance?

15. Do you get the impression that pilots feel any different after rubber has been removed?

16. Approximately how long does it take after rubber removal before you again notice rubber deposits in the touchdown area?

17. Do you have any other thoughts or comments on runway rubber build-up and removal?

18, Would you like a copy of the survey results? If so, please attach a business card.