A METHOD FOR DEVELOPING PRELIMINARY FRICTION DETERIORATION MODEL ON RUNWAY

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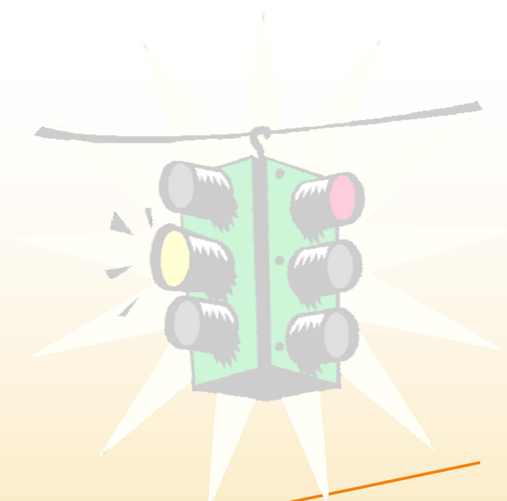


Introduction

The aim of this paper is, on one side, to set up a deteriorating model of friction, by analyzing lateral variability of a runway in a regional airport;
On the other side, to give a contribution to develop common measurement procedure.

Framework

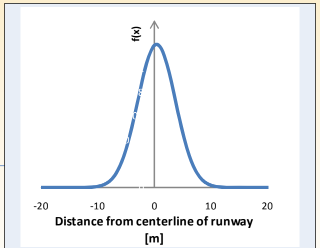
- Cumulative number of equivalent coverages (CECs) in the runway cross section points is calculated from input data (annual aircraft movements, traffic spectra, construction time and aircraft path distribution);
- Friction tests are run along several longitudinal paths in a single test session;
- Experimental results of friction tests are analysed for localizing homogeneous sections;

- **Runway is divided in 4 zone, bearing the landing phases in mind and to look at the mean friction value of the homogeneous sections (zone 1 *touchdown, zone 2 aircraft deceleration by ground spoiler and thrust reversers, zone 3 aircraft deceleration by wheel brakes and zone 4 approach to exit);***
- **A critical window (CW) containing only homogeneous sections (i.e. inside which there are not section border) and the lowest IFI values are identified in the four runway zones;**
- **Friction values in the CW are plotted versus CECs;**
- **Regression analysis is run for fitting deterioration model to experimental data.**

Maintenance Data
(Last construction or reconstruction work)

Aircraft Traffic Data
(traffic volume and spectra)

Coverage distribution in cross section



Distribution of take off and landing paths

Number of Cumulative Equivalent Coverages (CECs) at test time

FRICTION TESTS
(over several longitudinal paths)

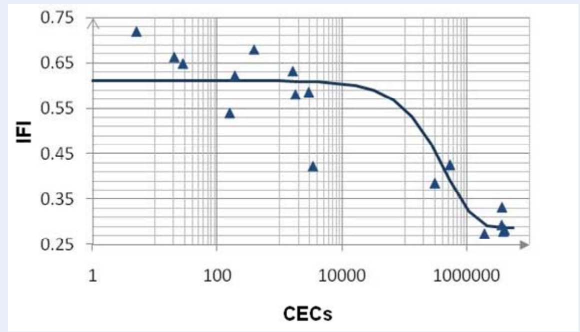
Test Analysis

Homogeneous Sections

CW identification in the 4 runway zones

Plot of experimental friction values versus CECs in the CWs

Regression analysis



Equivalent Coverages

Coverages (R) are numbers of times that a point on a runway is expected to be stressed by a wheel;
Equivalency Factor take into account the different damages produced by several aircraft types and gears

$$EC=R*EF$$

$$R_{nose}(x,y)=\begin{cases}\mathrm{lnw}_{nose} & \text{if } y\in\left\{\left[-\frac{i_{nose}}{2}-\frac{a_{nose}}{2}+x;-\frac{i_{nose}}{2}+\frac{a_{nose}}{2}+x\right]\cup\left[\frac{i_{nose}}{2}-\frac{a_{nose}}{2}+x;\frac{i_{nose}}{2}+\frac{a_{nose}}{2}+x\right]\right\}\\ 0 & \text{elsewhere}\end{cases}$$

$$R_{main\_left}(x,y)=\begin{cases}\mathrm{lnw}_{main} & \text{if } y\in\left\{\left[-\frac{i_{nose}}{2}-\frac{a_{nose}}{2}-d+x;-\frac{i_{nose}}{2}+\frac{a_{nose}}{2}-d+x\right]\cup\left[\frac{i_{nose}}{2}-\frac{a_{nose}}{2}-d+x;\frac{i_{nose}}{2}+\frac{a_{nose}}{2}-d+x\right]\right\}\\ 0 & \text{elsewhere}\end{cases}$$

$$R_{main\_right}(x,y)=\begin{cases}\mathrm{lnw}_{main} & \text{if } y\in\left\{\left[-\frac{i_{nose}}{2}-\frac{a_{nose}}{2}+d+x;-\frac{i_{nose}}{2}+\frac{a_{nose}}{2}+d+x\right]\cup\left[\frac{i_{nose}}{2}-\frac{a_{nose}}{2}+d+x;\frac{i_{nose}}{2}+\frac{a_{nose}}{2}+d+x\right]\right\}\\ 0 & \text{elsewhere}\end{cases}$$

lnw_{main} is the number of wheels along longitudinal direction of main landing gear (1, 2 or 3);
lnw_{nose} is the number of wheels along longitudinal direction of nose landing gear;
X is the distance of aircraft longitudinal axel from the runway centreline;
y is the distance of the surface point from the runway centreline;
i_{nose} is distance between nose landing gear wheels;
a_{nose} is diameter of nose landing gear wheel contact area;
i_{main} is distance between wheels of each main landing gear;
a_{main} is diameter of main landing gear wheel contact area;
d is distance between main landing gears.

$$R_{i\_take-off}(x,y)=R_{nose\_take-off}(x,y)+R_{main\_left\_take-off}(x,y)+R_{main\_right\_take-off}(x,y)$$

$$R_{i\_landing}(x,y)=R_{nose\_landing}(x,y)+R_{main\_left\_landing}(x,y)+R_{main\_right\_landing}(x,y)$$

$$PR_{i\_take-off}(y)=\int_{-\infty}^{+\infty} f_{take-off}(x)\cdot R_{i\_take-off}(x,y)dx$$

$$PR_{i\_landing}(y)=\int_{-\infty}^{+\infty} f_{landing}(x)\cdot R_{i\_landing}(x,y)dx$$

$$N_{i\_dec}(y)=n_{i\_dec}\cdot PR_{i\_dec}(y)$$

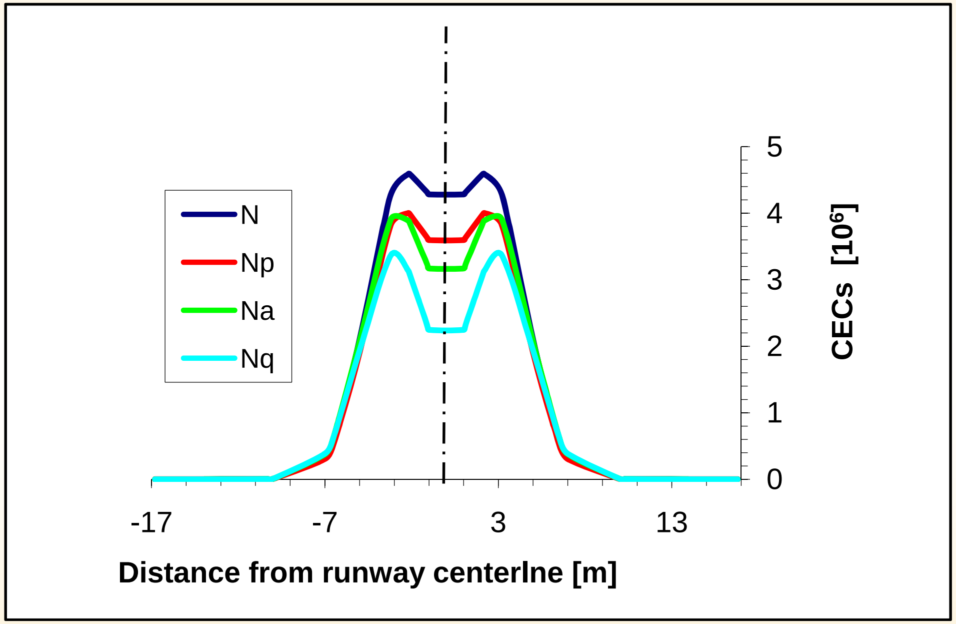
$$N_{i\_landing}(y)=n_{i\_landing}\cdot PR_{i\_landing}(y)$$

$$N_{tot\_take-off}(y)=\sum_i N_{i\_take-off}(y)$$

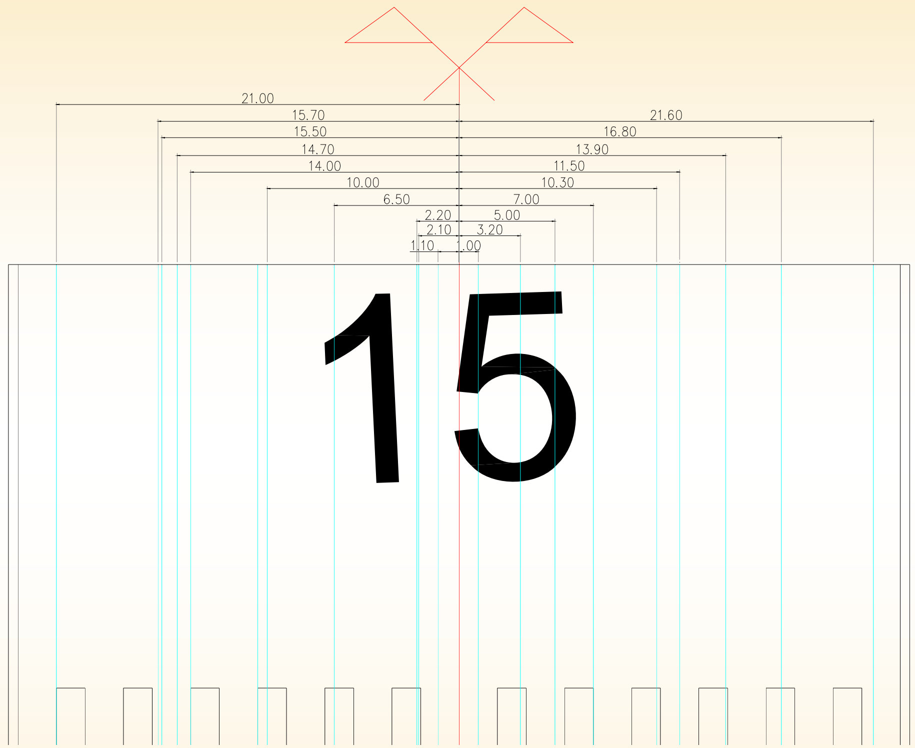
$$N_{tot\_landing}(y)=\sum_i N_{i\_landing}(y)$$

$$N_{TOT}(y)=N_{tot\_landing}(y)+N_{tot\_take-off}(y)$$

$$k_{i,j}^{p} = \frac{p_{i,j}}{p_{rv,rw}} \qquad k_{i,j}^{A} = \frac{A_{i,j}}{A_{rv,rw}} \qquad k_{i,j}^{L} = \frac{L_{i,j}}{L_{rv,rw}}$$



Pre wetting zone	braking	Friction measurements zone (locked wheel)	Releasing of brake	Braking	Friction measurements zone (locked wheel)	Releasing of brake
	5 m	10 m	5 m			

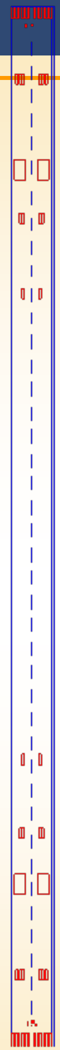


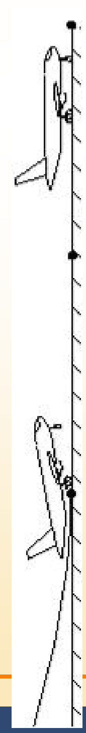
Distances from the runway centerline [m]																			
-21	-15.7	-15.5	-14.7	-14	-10.5	-10	-6.5	-2.2	-2.1	-1.1	1	3.2	5	7	10.3	11.5	13.9	16.8	21.6

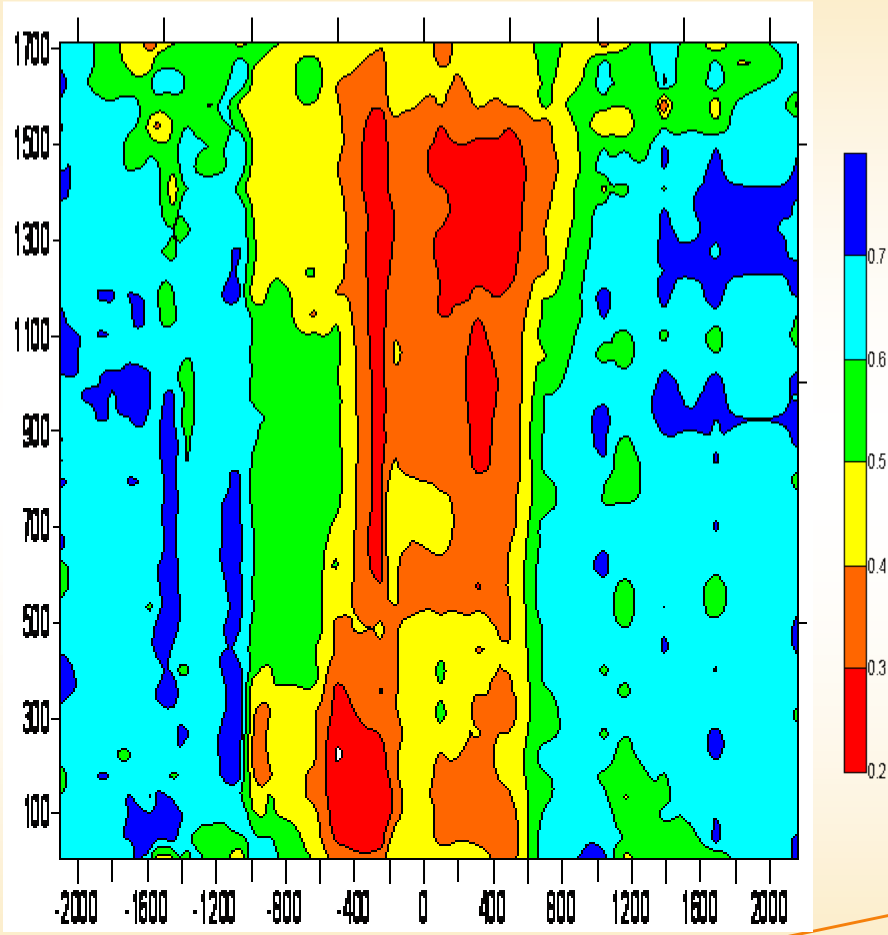
Fixed distance marks

Touch down zone

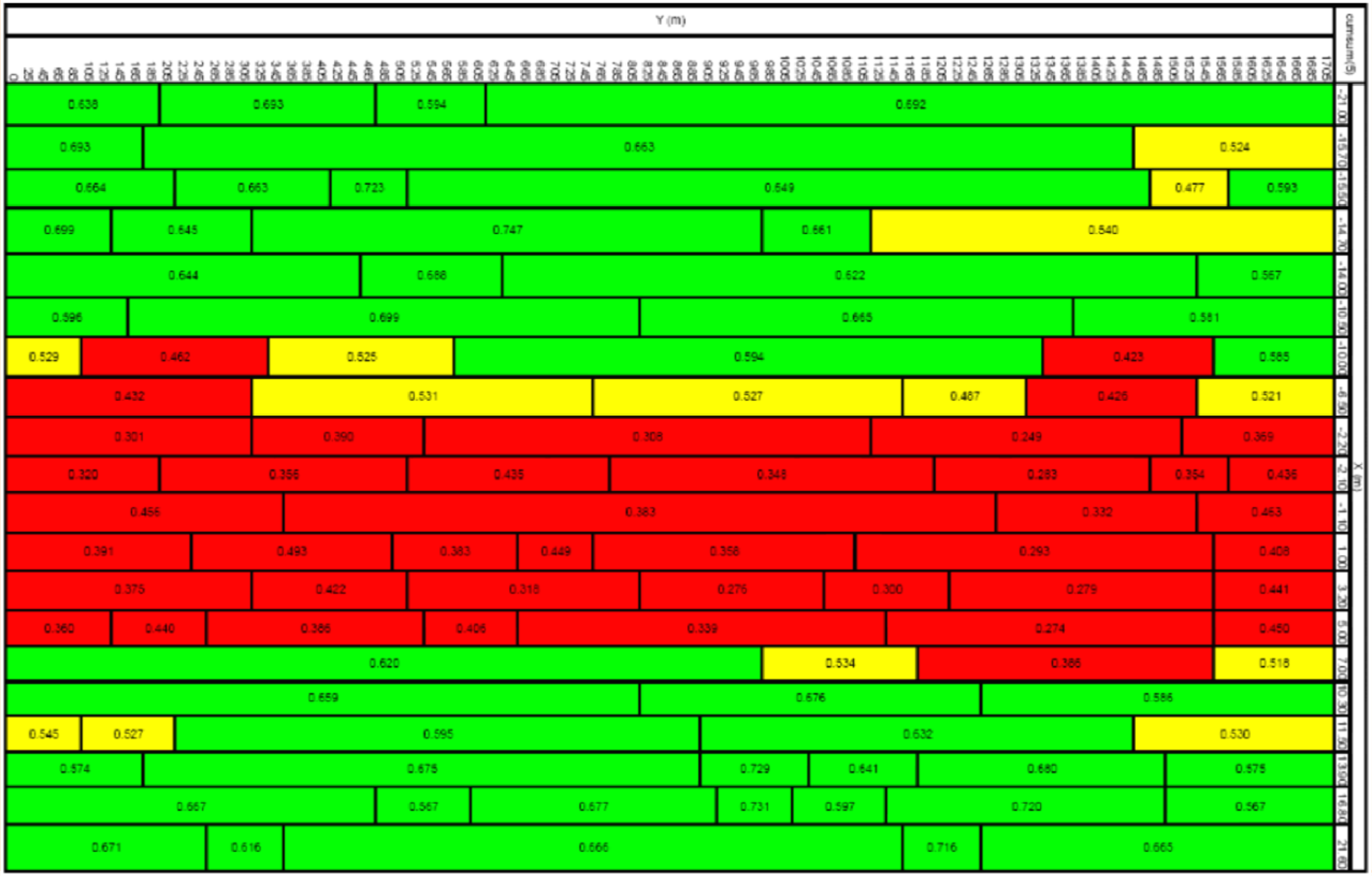
Threshold







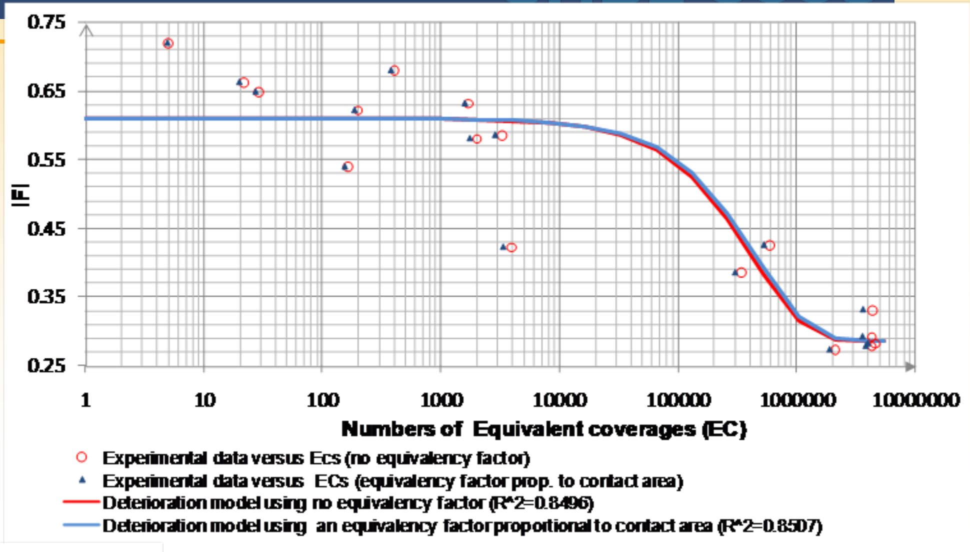
	Description	Distance from touch down marking of beginning and end of zone	Distance from touch down marking of beginning and end of CCS
Zone 1	touchdown	From 0 m to 300 m	From 105 m to 145 m
Zone 2	aircraft deceleration by ground spoiler and thrust reversers	From 300 m to 1200 m	From 985 m to 1025 m
Zone 3	aircraft deceleration by wheel brakes	From 1200 m to 1500 m	From 1385 m to 1465 m
Zone 4	approach to exit	From 1500 m to 1750 m	From 1585 m to 1700 m

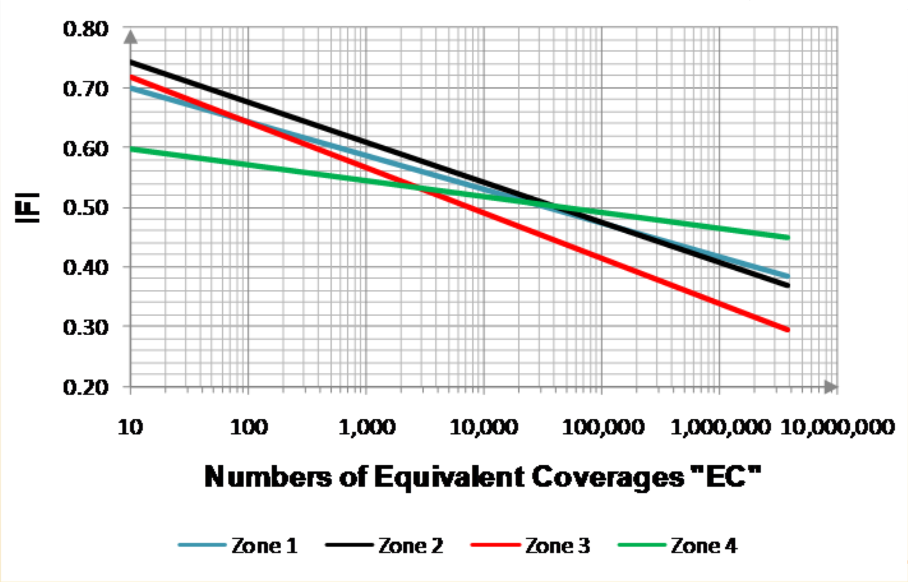

Y (m)
X (m)
0.638 0.693 0.594 0.692
0.693 0.663 0.524
0.664 0.653 0.723 0.649 0.477 0.593
0.699 0.645 0.747 0.661 0.540
0.644 0.686 0.622 0.567
0.596 0.699 0.665 0.581
0.529 0.462 0.525 0.594 0.423 0.585
0.432 0.531 0.527 0.487 0.426 0.521
0.301 0.390 0.308 0.249 0.369
0.320 0.355 0.435 0.348 0.283 0.354 0.436
0.456 0.383 0.332 0.453
0.391 0.493 0.383 0.449 0.356 0.293 0.408
0.375 0.422 0.318 0.276 0.300 0.279 0.441
0.360 0.440 0.366 0.406 0.339 0.274 0.450
0.620 0.534 0.366 0.518
0.659 0.676 0.586
0.545 0.527 0.595 0.632 0.530
0.574 0.675 0.729 0.641 0.680 0.575
0.667 0.567 0.677 0.731 0.597 0.720 0.567
0.671 0.616 0.666 0.716 0.665

$$IFI(EC) = a \cdot Log(EC) + b$$

$$IFI(EC) = a \cdot e^{-b \cdot (EC)} + c$$

		No equivalence factor		CEF proportional to contact area		CEF proportional to tyre pressure		CEF proportional to wheel load	
ZONE	parameter	logarithm model	shifted exponential model	logarithm model	shifted exponential model	logarithm model	shifted exponential model	logarithm model	shifted exponential model
VALUES OF THE MODEL PARAMETERS									
1	a	-0.055	0.2559	-0.056	0.264	-0.055	0.256	-0.057	0.299
	b	0.752	-1.20E-06	0.755	-9.81E-07	0.752	-1.33E-06	0.757	-7.23E-07
	c	-	0.3630	-	0.354	-	0.362	-	0.319
2	a	-0.065	0.3353	-0.066	0.347	-0.066	0.336	-0.067	0.376
	b	0.806	-1.06E-06	0.808	-9.08E-07	0.805	-1.16E-06	0.809	-7.97E-07
	c	-	0.3205	-	0.309	-	0.319	-	0.280
3	a	-0.073	0.3230	-0.075	0.324	-0.074	0.323	-0.076	0.326
	b	0.785	-2.29E-06	0.790	-2.12E-06	0.784	-2.56E-06	0.793	-2.03E-06
	c	-	0.2869	-	0.286	-	0.287	-	0.284
4	a	-0.026	0.1480	-0.026	0.162	-0.026	0.150	-0.026	0.175
	b	0.624	-6.97E-07	0.624	-5.74E-07	0.623	-7.53E-07	0.624	-5.81E-07
	c	-	0.4162	-	0.402	-	0.414	-	0.389
SUM OF SQUARE OF THE RESIDUALS (SSR)									
1		0.0750	0.0762	0.0762	0.0757	0.0747	0.0760	0.0775	0.0732
2		0.0792	0.0174	0.0837	0.0167	0.0786	0.0173	0.0879	0.0152
3		0.0479	0.0714	0.0482	0.0709	0.0481	0.0715	0.0490	0.0703
4		0.0274	0.0109	0.0288	0.0108	0.0272	0.0109	0.0300	0.0108
COEFFICIENT OF DETERMINATION (R^2)									
1		0.7613	0.7574	0.7574	0.7589	0.7621	0.7580	0.7532	0.7671
2		0.8110	0.9583	0.8001	0.9601	0.8123	0.9586	0.7901	0.9638
3		0.8991	0.8496	0.8985	0.8507	0.8987	0.8493	0.8969	0.8519
4		0.6653	0.8661	0.6482	0.8683	0.6669	0.8664	0.6334	0.8677


0.75
0.65
0.55
0.45
0.35
0.25
|F|
1
10
100
1000
10000
100000
1000000
10000000
Numbers of Equivalent coverages (EC)
Experimental data versus Ecs (no equivalency factor)
Experimental data versus ECs (equivalency factor prop. to contact area)
Deterioration model using no equivalency factor (R^2=0.8496)
Deterioration model using an equivalency factor proportional to contact area (R^2=0.8507)


0.80
0.70
0.60
0.50
0.40
0.30
0.20
|F|
10
100
1,000
10,000
100,000
1,000,000
10,000,000
Numbers of Equivalent Coverages "EC"
Zone 1
Zone 2
Zone 3
Zone 4

CONCLUSIONS

Experimental survey allowed us to map friction on runway;
The minimum value of friction was localized in the second half of the runway (700 to 1400 m), at a distance from centerline between 2 and 4 m, where the coverages are maximum!!
Furthermore models, constructed using statistical regression, fit well experimental data, and the Indipendent Variable "Equivalent Coverage" seems to represent quite well actions of several aircraft types.