



ESDU TECHNICAL MEMORANDUM

Analysis of aircraft tests on flooded runways: an empirical approach

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ESDU TECHNICAL MEMORANDA

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ANALYSIS OF AIRCRAFT TESTS ON FLOODED RUNWAYS: AN EMPIRICAL APPROACH

CONTENTS

	Page
1. NOTATION AND DEFINITIONS	1
1.1 Notation	1
2. INTRODUCTION	3
3. MODELLING	3
3.1 General	3
3.2 Displacement force	5
3.3 Impingement	6
3.3.1 General	6
3.3.2 Empirical study	7
3.4 Analysis process	8
4. EXAMPLE: THE CESSNA CITATION II	9
4.1 General	9
4.2 Analysis	10
4.2.1 Nose-undercarriage alone	10
4.2.2 Main-undercarriage alone	11
4.2.3 Full undercarriage	11
4.3 DISCUSSION	11
5. CONCLUDING REMARKS	12
6. REFERENCES	12
FIGURES 1-9	13-21

ANALYSIS OF AIRCRAFT TESTS ON FLOODED RUNWAYS: AN EMPIRICAL APPROACH

1. NOTATION AND DEFINITIONS

1.1 Notation

Symbol	Meaning	Dimensions
b	half-width of tyre footprint (see Sketch (3.1))	L
$(C_D)_{DISP}$	coefficient of decelerating force due to displacing contaminant	–
$(C_D)_{IMP}$	coefficient of decelerating force due to impingement of displaced fluid on airframe	–
$((C_D)_{IMP})_M$	coefficient of decelerating force due to impingement of fluid displaced by main undercarriage on airframe	–
$((C_D)_{IMP})_N$	coefficient of decelerating force due to impingement of fluid displaced by nose undercarriage on airframe	–
C_L	coefficient of lift	–
d_C	water depth	L
d_{TEX}	depth of surface macro-texture	L
D	inflated diameter of tyre	L
G	decelerating force	MLT^{-2}
G_{DISP}	decelerating force due to displacing contaminant	MLT^{-2}
$(G_{DISP})_M$	decelerating force due to displacing contaminant for a main undercarriage	MLT^{-2}
$(G_{DISP})_N$	decelerating force due to displacing contaminant for a nose undercarriage	MLT^{-2}
G_{FLUID}	decelerating force due to rolling in fluid contaminant	MLT^{-2}
G_{IMP}	decelerating force due to impingement of displaced fluid on airframe	MLT^{-2}
$(G_{IMP})_M$	decelerating force due to impingement of fluid displaced by main undercarriage on airframe	MLT^{-2}
$(G_{IMP})_N$	decelerating force due to impingement of fluid displaced by nose undercarriage on airframe	MLT^{-2}
m	mass of displaced contaminant	M
m	number of wheels in line-astern arrangement	–

N	speed number ($= \rho_c V_G^2 / (\pi p_{ABS})$)	–
n	number of wheels in a line-abreast arrangement	–
p	inflation pressure relative to ambient pressure	$ML^{-1}T^{-2}$
p_{ABS}	inflation pressure in absolute measure	$ML^{-1}T^{-2}$
p_M	inflation pressure of tyre from main undercarriage (gauge)	$ML^{-1}T^{-2}$
p_N	inflation pressure of tyre from nose undercarriage (gauge)	$ML^{-1}T^{-2}$
q	kinetic pressure	$ML^{-1}T^{-2}$
q_A	kinetic pressure of air	$ML^{-1}T^{-2}$
S_F	area of tyre footprint	L^2
S_{REF}	reference area of wing	L^2
t	time	T
V	speed	LT^{-1}
V_G	ground speed	LT^{-1}
V_T	true airspeed	LT^{-1}
W	weight of aircraft	MLT^{-2}
w	inflated width of tyre	L
y	distance between centre-lines of tyres in line-abreast	L
Z	vertical load on tyre	MLT^{-2}
Z_M	vertical load on a main undercarriage	MLT^{-2}
Z_N	vertical load on nose undercarriage	MLT^{-2}
Z_{TOT}	net vertical aircraft load (weight minus lift)	MLT^{-2}
Z_{UC}	vertical load on undercarriage	MLT^{-2}
$E[\]$	expected value of quantity in []	–
$\Phi[\]$	correlating function using quantity in []	–
$M[\]$	measured value of quantity in []	–
β_F	flap settings (in degrees)	–
ρ_A	density of air	ML^{-3}
ρ_C	density of water	ML^{-3}
$1/\tau$	surface drainage parameter ($= d_C / (d_{TEX} + d_C)$)	–

2. INTRODUCTION

The additional decelerating force that affects an aircraft when **rolling** on a runway contaminated by a layer of water consists of two components: one major, and one minor but important. The major component arises from the work done by the tyres in displacing the water from the track; it is customary to refer to that force as **displacement**. This effect is covered in detail in References 1 and 2 for single wheels and in Reference 3 for multiple wheel undercarriages. The minor component arises from impingement of any spray (generated in the process of displacing the fluid contaminant) on to parts of the airframe: it is customary to refer to the force as **impingement**. A start has been made in Reference 4; there a speed-related function is identified for the form of the force. Such a concept, if it were sufficiently broad in its application to a range of aircraft, may be useful in developing a general (algebraic) treatment of spray.

In this note, the concept is developed as part of an empirical scheme and is then considered as an aid to analysing aircraft tests. Data from testing one aircraft when rolling (*but not braking*) in troughs filled with significant depths of water are appraised. Displacement forces are calculated using the methods of References 1, 2, and 3 and are subtracted from the total fluid forces. The residual (impingement) forces are then studied in terms of the algebraic description introduced in Reference 4.

3. MODELLING

3.1 General

Following customary practice, it is supposed that, on an aircraft, the decelerating force (G_{FLUID}) that arises from rolling through water is made up of two parts* so that:

$$G_{FLUID} = G_{DISP} + G_{IMP} , \quad (3.1)$$

where G_{DISP} is the decelerating force due to displacing contaminant and

G_{IMP} is the decelerating force due to impingement of displaced fluid on the airframe.

In which it is assumed that the displacement component is the simple sum of the displacement forces from the nose and main undercarriages.

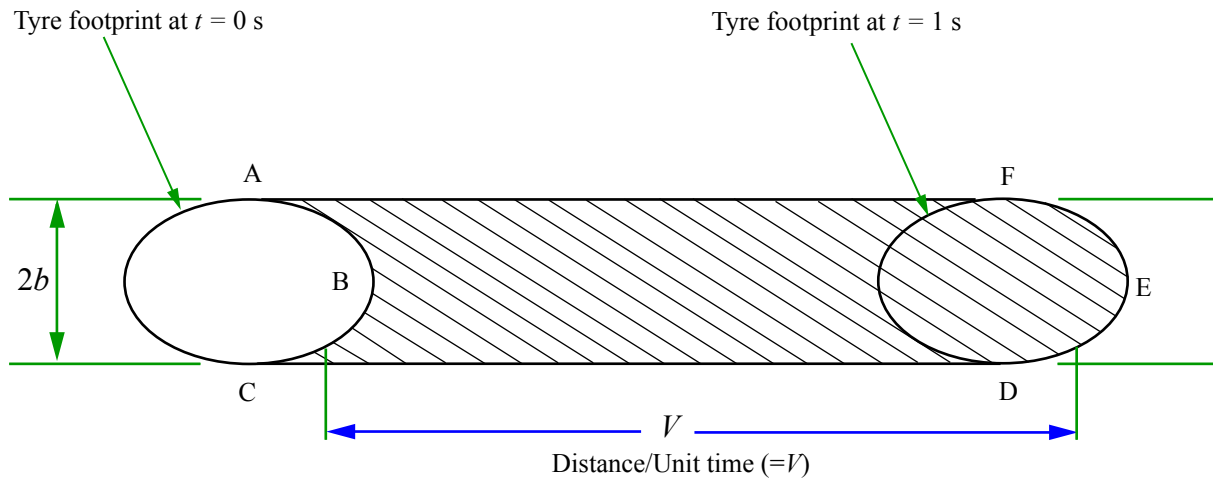
Recapitulate the modelling process for force as set down in Reference 2 and extend it to include both impingement and displacement. Consider the diagram in Sketch 3.1. In unit time the area of contaminant (in this case water) ABCDEFA is swept by the tyre.

This swept area (*per unit time*) is the product of footprint width ($2b$) and ground speed. So, the volume of fluid displaced from under the footprint in unit time is the product of swept area ($2bV$, where $V = V_G$) and water depth (d_C). Further, the mass of displaced fluid is the product of volume and density. Thus, the mass displaced *per unit time* is

$$dm/dt = \rho_C d_C 2bV_G , \quad (3.2)$$

where ρ_C is the density of water.

* Note that for the case where the contaminant is slush there is a third resistive force component due to the compression of the slush under the tyre footprint, G_{COM} .



Sketch 3.1 Layout of tyre movement

It may be supposed that the *mean* velocity imparted to the fluid particles is proportional to the translation speed of the footprint over the ground. Then, the total time rate of change of linear momentum imparted to the water is

$$G_{FLUID} \propto \frac{dm}{dt} V_G \propto 2\rho_C d_C b V_G^2 . \quad (3.3)$$

To determine the effective width of the footprint, consider the area of the footprint. It is shown in Reference 2 that

$$S_F = Z / p_{ABS} , \quad (3.4)$$

where p_{ABS} is the tyre inflation pressure (absolute measure) and

Z is the vertical load acting on the tyre.

It is supposed that changes in vertical force and/or inflation pressure result in geometrically similar footprints; that is, the size of the footprint changes but not its shape. Then

$$S_F \propto b^2 \text{ or } b \propto (Z / p_{ABS})^{1/2} . \quad (3.5)$$

Thus, from Equations (3.3) and (3.5),

$$G_{FLUID} \propto \rho_C d_C (Z / p_{ABS})^{1/2} V_G^2 . \quad (3.6)$$

Or given $q = \rho_C V_G^2 / 2$, and writing Equation (3.1) in terms of coefficients of both displacement force and impingement force,

$$G_{FLUID} \propto q d_C (Z / p_{ABS})^{1/2} \{ (C_D)_{DISP} + (C_D)_{IMP} \} . \quad (3.7)$$

where $(C_D)_{DISP}$ is the coefficient of decelerating force due to displacing contaminant,

$(C_D)_{IMP}$ is the coefficient of decelerating force due to impingement of displaced fluid on airframe and

q is the fluid kinetic pressure.

The coefficients in Equation (3.7) are to be deduced from experimental data.

It is noted that the arguments leading to Equation (3.7) for a single tyre include consideration of speed, water depth, aircraft weight, aerodynamic lift, and inflation pressure. There is some experimental evidence, put to use in Reference 2, that extends the methods for displacement to contaminants other than water. It is not clear that similar extensions can be made when impingement is considered.

3.2 Displacement force

Using the methods for **rib-tread** tyres set down in References 1, 2, and 3 and therefore accounting for the possibility of an undercarriage leg carrying wheels in line-abreast,

$$G_{DISP} = q d_C (Z / p_{ABS})^{1/2} \Phi[y/w] (C_D)_{DISP}, \quad (3.8)$$

where w is the width of an inflated tyre and

y is the distance between centre-lines of tyres in line-abreast.

The coefficient of decelerating force due to displacing contaminant is calculated using Equation (3.9).

$$(C_D)_{DISP} = c_0 \tanh \left[\left(\frac{c_1}{N^2/\tau^2} \right) \right], \quad (3.9)$$

where N is the speed number and

$1/\tau$ is the surface drainage parameter.

The c_0 term is calculated using Equation (3.10).

$$c_0 = \left(\frac{w/D}{c_{01}} \right)^2, \quad (3.10)$$

where c_{01} is a constant (see Table 3.1) and

D is the diameter of an inflated tyre.

For a rib-tread tyre, the c_1 term is calculated using Equation (3.11).

$$c_1 = c_{11} / \left(1 + \left(\frac{w/D}{c_{12}} \right)^2 \right), \quad (3.11)$$

where c_{11} and c_{12} are constants (see Table 3.1).