



ESDU TECHNICAL MEMORANDUM

Analysis of ground-rolling tests through water with a Canberra aircraft

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ESDU TECHNICAL MEMORANDA

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ANALYSIS OF GROUND-ROLLING TESTS THROUGH WATER WITH A CANBERRA AIRCRAFT

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ANALYSIS OF GROUND-ROLLING TESTS THROUGH WATER WITH A CANBERRA AIRCRAFT

1. NOTATION, UNITS AND DEFINITIONS

1.1 Notation

		Units
C_D	coefficient of decelerating force due to fluid displacement by single tyre	—
c_0, c_1	coefficients in model of coefficient of decelerating force	—
D	inflated diameter of tyre	ft
d_C	depth of water	ft
d_{TEX}	depth of surface macro-texture	ft
G_{COM}	fluid decelerating force due to compression of medium	lbf
G_{DISP}	decelerating force due to displacement of fluid	lbf
G_{FLUID}	decelerating force due to single wheel passing through fluid	lbf
G_I	decelerating force due to impingement of spray on airframe	lbf
$(G_I)_{REF}$	reference decelerating force due to impingement of spray on airframe	lbf
N	speed number	—
p	tyre inflation pressure gauge	lbf/ft ²
p_{ABS}	tyre inflation pressure absolute	lbf/ft ²
q	kinetic pressure	lbf/ft ²
V_G	ground speed	ft/s
$\text{var}[\]$	variance of quantity in []	—
Z	normal (to runway) load on wheel	lbf
$\Delta[\]$	deviation of measured value of quantity in [] from model	—
$\delta[\]$	normalised deviation of measured value of quantity in [] from model	—
$E[\]$	expected value of quantity in [] from model	—
$M[\]$	measured value of quantity in []	—
$\sigma[\]$	standard error of quantity in []	—
$1/\tau$	runway drainage parameter	—
χ^2	statistical test	—

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1.2 Definitions

<i>Speed number</i>	is the square root of the ratio of kinetic pressure and that (kinetic) pressure at which a <i>smooth</i> tyre leaves a <i>smooth</i> surface.
<i>Tyre footprint</i>	is the region of contact between a pneumatic tyre and an external medium.

2. INTRODUCTION

2.1 General

A series of tests on a Canberra aircraft was conducted at the Cranfield Institute of Technology and reported in Reference 1. In that report it is made clear that there is impingement of spray from the nose-wheel and (crucially) the main wheels, on to the airframe. It is therefore not correct to ignore forces due to this impingement. So the inclusion of Canberra data in the documentation for the development of the modelling for the passage of tyres through fluid media was not appropriate in the form that was presented in Reference 2.

That is not to say that the data are of no use in establishing the general validity of the methods under development. It is feasible to estimate the effect of tyre fineness ratio from tests on single rib-tread tyres and so to demonstrate that the measurements on the Canberra aircraft are plausibly modelled. Of course, such a scheme depends on identifying a suitable representation of the impingement forces.

This memorandum contains a simple extension to the modelling for single wheels in water that is applicable for the *specific configuration of the Canberra*. The form of the extension may be of use should it become necessary to revisit the methods for impingement forces already published by ESDU.

2.2 Modelling

The force on a single wheel, G_{FLUID} , passing through a fluid medium is defined in Section 5 of ESDU 10015 (Reference 3) and consists of two components

$$G_{FLUID} = G_{COM} + G_{DISP}, \quad (2.1)$$

in which G_{COM} is a force arising from compressing the fluid under the footprint (where appropriate) and G_{DISP} is a force arising from displacing the fluid from the path of the wheel. When considering the case of a wheel and under-carriage attached to an airframe, it is necessary to include a further source of decelerating force, that due to impingement of spray onto the airframe. The decelerating force is then given by

$$G_{FLUID} = G_{COM} + G_{DISP} + G_I. \quad (2.2)$$

The set of data considered in this memorandum is for motion through water. There is therefore no component due to compression as water is an incompressible medium. In order to identify the effect of impingement it is assumed that decelerating force due to displacement is given by (see ESDU 10015, Reference 3)

$$E[G_{DISP}] = q d_C \left(\frac{Z}{p_{ABS}} \right)^{1/2} C_D. \quad (2.3)$$

Decelerating force coefficient is calculated, as given in ESDU 10015 (Reference 3), by

$$C_D = c_0 \tanh \left[\left(c_1 / \frac{N^2}{\tau^2} \right)^2 \right]. \quad (2.4)$$

The Canberra tests were conducted on a specially prepared part of the runway at the Cranfield Institute of Technology in 1969. At that time it was common practice to prepare very smooth surfaces for most airfields. It is assumed that the surface was prepared with a macro-texture depth so that $d_{TEX} = 0.01$ inch, then the runway drainage parameter $1/\tau$ has a value different from unity at values of water depth approaching zero. The importance of this will be explained in Section 4.

The impingement decelerating force is defined as the difference between the measured fluid decelerating force and the calculated decelerating force due to displacement and so

$$G_I = M[G_{FLUID}] - E[G_{DISP}]. \quad (2.5)$$

Figures 1, 2 and 3 chart the result of solving Equation (2.5) for the most extensive sets of tests made at a nominal water depth of one inch over a speed range so that $60 < V_G \text{ (ft/s)} < 170$. Included on the charts is the function

$$G_I = (G_I)_{REF} \left(\frac{N^2}{\tau^2} \right)^2 \tanh \left[1 / \left(\frac{N^2}{\tau^2} \right)^3 \right], \quad (2.6)$$

in which $(G_I)_{REF} = 350$ lbf. The function is discussed in Section 4.

Figures 4 to 10 chart data from the flight test report. The figures are organised to illustrate the effects of speed, inflation pressure, and water depth on the decelerating force due to a single main-wheel rolling through water. Calculations from the modelling described in Equations (2.3) to (2.6) are also shown in the figures. Effects (on estimates of decelerating force) of uncertainty in measuring the four independent variables are also shown on the figures. Calculation of these effects is considered in Section 3.

3. ANALYSIS OF UNCERTAINTY

3.1 Uncertainty in Measurement

Reasonable attention is paid in the flight-test report to the precision of the various measurements. In principle, the requirements for such a series of tests are to measure decelerating force, ground-speed, tyre pressure, normal force and water depth. At the time of testing, it was not regarded as necessary to consider depth of macro-texture of the surface.

Decelerating force was measured using an accelerometer aligned with the aircraft longitudinal datum. An attitude gyroscope was also fitted so that adjustments could be made for any excursions in pitch that may have occurred. The resolution of the accelerometer is deduced from the following. Total range of the accelerometer is quoted to be 0.5 g -units and assuming that resolution on the paper film is one per cent of total range, then resolution of accelerometer reading is 0.005 g -units.