



ESDU TECHNICAL MEMORANDUM

Falcon 20: rolling on dry and snow-covered surfaces

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ESDU TECHNICAL MEMORANDA

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FALCON 20: ROLLING ON DRY AND SNOW-COVERED SURFACES

CONTENTS

	Page
1. NOTATION	1
2. AERODYNAMIC MODEL	4
2.1 Introduction	4
2.2 Forces Normal to Runway	4
2.3 Forces Parallel to Runway	5
2.4 Results	7
3. APPLICATION TO OPERATIONS ON SNOW-COVERED RUNWAYS	9
3.1 General	9
3.2 Forces Due to Presence of Snow on Runway	9
3.3 Calculated Acceleration	10
3.4 Discussion	10
4. CONCLUDING REMARKS	10
5. REFERENCES	11
FIGURES 1 to 20	12 to 21

FALCON 20: ROLLING ON DRY AND SNOW-COVERED SURFACES

1. NOTATION

		Dimension
A	total area of cross-section of inlet stream tubes	L^2
a	acceleration	LT^{-2}
C_D	drag coefficient	—
C_L	lift coefficient	—
D	aerodynamic force parallel to air path	MLT^{-2}
d	depth	L
G	force parallel to runway	MLT^{-2}
G	effective shear modulus or modulus of rigidity	$ML^{-1}T^{-2}$
g	acceleration due to gravity	LT^{-2}
k	factor on inlet mass flow ratio	—
L	aerodynamic lift	MLT^{-2}
$(dm/dt)_0$	mass flow rate through intake pre-entry streamtube (at freestream conditions)	MT^{-1}
$(dm/dt)_1$	mass flow rate through intake capture area (at freestream conditions)	MT^{-1}
n	number of wheels	—
$Pr[\]$	probability of function in $[\]$	—
p_{ABS}	inflation pressure, absolute	$ML^{-1}T^{-2}$
p_a	ambient pressure, absolute	$ML^{-1}T^{-2}$
q	kinetic pressure	$ML^{-1}T^{-2}$
S	reference area	L^2
s	distance travelled parallel to runway	L
t	time	T
V	speed	LT^{-1}
V_G	ground speed	LT^{-1}
V_T	true airspeed	LT^{-1}
W	weight	MLT^{-2}
X_G	gross thrust	MLT^{-2}

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Z	normal (to runway) load	MLT^{-2}
Z_M	normal (to runway) load on one main-wheel	MLT^{-2}
Z_N	normal (to runway) load on one nose-wheel	MLT^{-2}
β	flap deflection	—
$\Delta[\]$	deviation of measurements from correlation	—
δ	airbrake position	—
$E[\]$	mean (or expected) value of quantity in $[\]$	—
ε	runway slope (positive “up-hill”)	rad
θ	empirical motion efficiency (see Equation (6.24) in Reference 2)	—
Λ	tyre loading parameter	—
λ	proportion of vertical load carried by nose-undercarriage	—
κ	tyre construction parameter	—
μ	coefficient of decelerating force parallel to runway	—
ρ	density	ML^{-3}
$\sigma[\]$	standard error of quantity in $[\]$	—
$1/\tau$	surface drainage parameter ($= d_C/(d_C + d_{TEX})$)	—
ϕ_β	coefficient in correlation of decelerating force	—
ϕ_δ	coefficient in correlation of decelerating force	—
χ^2	test statistic	—

Suffices

<i>AFTB</i>	aircraft afterbody
<i>AIRB</i>	aircraft airbrake
<i>AIRF</i>	airframe of aircraft
<i>C</i>	contaminant
<i>COM</i>	compression or compressed
<i>DATUM</i>	datum
<i>FLAP</i>	flaps
<i>i</i>	relates to <i>M</i> or <i>N</i>
<i>M</i>	main undercarriage
<i>MOM</i>	momentum

<i>N</i>	nose undercarriage
<i>POWER</i>	power from power units
<i>ROLL</i>	rolling resistance
<i>RUT</i>	relates to rut depth in snow
<i>SNOW</i>	snow
<i>SPILL</i>	spillage
<i>TEX</i>	effective surface macro-texture
<i>TREAD</i>	refers to materials in tyre-tread
0	conditions in free-stream
1	conditions at plane of inlet

2. AERODYNAMIC MODEL

2.1 Introduction

At the beginning of the joint research programme conducted by Transport Canada and other agencies, two flights of the Falcon 20 were devoted to the determination of the balance of longitudinal forces on an uncontaminated runway with engines at idle. In the analysis of Reference 1, it was assumed that brochure thrust and aerodynamic drag were known and the balance of forces was achieved by solving for rolling resistance. A linear variation of the coefficient of rolling resistance with speed was identified. This strategy was adopted in the absence of a convincing method for estimating the coefficient of rolling resistance.

As part of the modelling summarised in Reference 2 a straightforward method to estimate this coefficient is defined. Given this method and assuming that lift coefficient is known, it is therefore possible to analyse the tests of Reference 1 in such a way as to determine aerodynamic drag coefficient and forces due to the power units.

Charts of speed and acceleration against time are presented in Reference 1. These data have been digitised and have been used to establish a model of the Falcon 20 within a plausible framework. The framework is set out in this memorandum together with a justification of the format used.

2.2 Forces Normal to Runway

The total normal load on the undercarriage is the total weight less the aerodynamic lift, given by

$$Z = W \cos[\varepsilon] - 0.5 \rho S V_T^2 C_L . \quad (2.1)$$

This vertical load is distributed between the four wheels on the main undercarriage and the two wheels on the nose undercarriage. It is assumed that the nose undercarriage carries a proportion, λ ($= 0.1$), of the total load. The load carried by one wheel on the nose undercarriage is

$$Z_N = \frac{\lambda Z}{n_N} . \quad (2.2)$$

Also, the load carried by one wheel on the main undercarriage is

$$Z_M = \frac{(1 - \lambda) Z}{n_M} . \quad (2.3)$$

For each configuration of flap and airbrake tested, the lift coefficient at the ground angle of attack has its own value taken from Reference 1. These are listed in Table 2.1.

Although the vertical loads assumed for each tyre are approximations, the effects of quite large errors are not serious. This is because the vertical force balance is used only to estimate the coefficient of rolling resistance. In the correlation of Reference 2 only the cube root of the normal force appears.

TABLE 2.1 Conditions covered in testing for aerodynamic data

<i>Flight</i>	<i>Flap</i>	<i>Airbrake</i>	<i>C_L</i>	<i>Power</i>	<i>Runway condition</i>	<i>Speed range</i>
96-04	15	In	0.2	Idle	Wet	$10 < V_G \text{ (kn)} < 100$
96-04	15	Out	0.1	Idle	Wet	$50 < V_G \text{ (kn)} < 90$
96-04	40	Out	0.3	Idle	Wet	$45 < V_G \text{ (kn)} < 90$
96-10	15	In	0.2	Idle	Dry	$60 < V_G \text{ (kn)} < 120$
96-10	15	Out	0.1	Idle	Dry	$45 < V_G \text{ (kn)} < 115$
96-10	40	Out	0.3	Idle	Dry	$40 < V_G \text{ (kn)} < 95$

2.3 Forces Parallel to Runway

It is assumed that the axes of the final propelling nozzles are parallel to the runway when the aircraft is in its ground attitude. Then, the balance of forces parallel to the runway can be represented by

$$-W \left(\frac{dV/dt}{g} + \sin[\varepsilon] \right) + X_G - D_{POWER} - D_{AIRF} - G_{ROLL} = 0, \quad (2.4)$$

in which the drag force arising from operation of the power units is given by

$$D_{POWER} = D_{MOM} + D_{SPILL} + D_{AFTB}. \quad (2.5)$$

The airframe drag comprises

$$D_{AIRF} = D_{DATUM} + D_{FLAP} + D_{AIRB}. \quad (2.6)$$

The rolling resistance is

$$G_{ROLL} = n_N Z_N (\mu_{ROLL})_N + n_M Z_M (\mu_{ROLL})_M. \quad (2.7)$$

Coefficients of rolling resistance are, from the correlation in Reference 2, given by

$$(\mu_{ROLL})_i = \lambda_0 \left(1 + \left(\frac{\rho_{TREAD} V_{ROLL}^2}{G_{TREAD}} \right)^{1/3} \left(\frac{\varepsilon \rho_{TREAD} V_{ROLL}^2}{\kappa p_{ABS}} \right)^{2/3} \right) \Lambda_i^{1/3}, \quad i = M \text{ or } N, \quad (2.8)$$

in which
$$\Lambda_i = \frac{Z_i / (\pi w_i D_i)}{\kappa (p_{ABS})_i}.$$