DEVELOPMENT OF SMALL-SCALE SNOWDRIFT SIMULATION

By

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INTRODUCTION

The formation of snow-drifts around an obstacle situated within the atmospheric boundary layer constitutes an exceedingly complex two-phase flow problem, one that does not prove readily calculable. Consequently, it is usually necessary to determine drift geometry by physical means. It is considerably less expensive and quicker to test a small-scale model than to build a full-scale physical system and wait for an appropriate snowstorm. Thus a considerable number of laboratory experiments has been conducted, beginning with Finney's wind tunnel experiments (1934, 1937, 1939, 1940) which have served as the basis for subsequent highway design.

Other wind tunnel experiments have been performed by Anfilofev (1973), Anno (1981), Becker (1944), Brier (1968, 1972), Gerdel and Strom (1961), Strom et al. (1962), Iversen (1980a, 1980b, 1980c, 1981), Ring et al. (1979), Kimura and Yoshisaka (1971), Kind and Murray (1980), Kreutz and Walter (1956), Mateescu and Popescu (1974), Negoita and Mateescu (1969), Nøkkentved (1940), Jensen (1959), Sherwood (1967), Stehle (1964), and Wianecki (1976). Snow drift simulations in water have been performed by Calkins (1974a, 1974b, 1975), de Krasinski (1975, 1979), Isyumov (1971, 1974), Norem (1975), Theakston (1962, 1967, 1969, 1970, 1975), and Wuebben (1978). A carefully performed set of experiments in the atmosphere on a frozen lake surface using natural snow has been reported by Tabler (1980) and Tabler and Jairell (1980). Tobiasson and Reed (1966) have also performed outdoor modeling at small scale. Interesting simulations of snow avalanches have been performed using water and brine (Beghin and Hopfinger, 1978; Hopfinger and Tochon-Danguy, 1977).

THE SIMILITUDE PROBLEM

The primary question for small-scale modeling, of course, is one of similitude, i.e., whether full-scale events can be accurately predicted from measurements on a model. For many of the experiments mentioned above, similitude requirements were not discussed. Among those who have reviewed the similitude requirements for snowdrift models are de Krasinski and Anson (1979), Dyunin (1973), Gerdel and Strom (1961), Imai (1949), Isyumov (1971), Iversen (1979, 1980a, 1982), Kind (1976), Norem (1975), Odar (1962, 1965), and Tabler (1980).

The similitude problem is exceedingly complex. There are so many significant problem variables that the employment of dimensional analysis alone is not much help. This writer has used, in addition, the dimensionless particle equations of motion and expressions for mass transport rate in saltation to aid in grouping the basic dimensionless parameters. Since the model is necessarily distorted, these groups of parameters are used to determine the degree of distortion and its effect on time-dependent drift geometry.

Paper presented at the Western Snow Conference, 1982.

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From a combination of theory and experiment, the following semi-empirical relationship has evolved:

$$q_d g/\rho u_*^2(u_* - u_{*t}) = f(\rho/\rho_p,\ u_*^2/gh,\ U_f/u_{*t},\ u(h)L/\nu,\ \text{geometric similarity}) \qquad (1)$$

In this equation, q_d is either mass deposition rate or deflation rate, depending upon what is being measured. The Reynolds number $u(h)L/\nu$ is usually a minimum criterion, and the geometric similarity should include a nonerodible topographic roughness criterion. The particle parameter U_f/u_{*t} is the ratio of terminal speed to threshold friction speed and is a measure of how easily a particle is suspended by turbulence upon becoming airborne (Iversen, 1976). The other two parameters, the density ratio and Froude number, affect the effective roughness height in saltation and the concentration of particle mass near the surface, which in turn affect the deposition or deflation rate. How these parameters interact is not yet entirely clear. What does seem to be clear is that the form of the functional relationship among the variables of Equation (1) is very much configuration dependent.

An example of the application of Equation 1 is shown in Figure 1. This shows the dimensionless deposition rate of Equation 1 as a function of density ratio and Froude number for an interstate highway bridge model (Iversen 1980a, Ring et al., 1979). The dimensionless deposition rate is seen to decrease with increase in density ratio ρ/ρ_p and Froude number u_*^2/gh. This is to be expected if the deposition rate is less than the total mass transport (Iversen 1982).

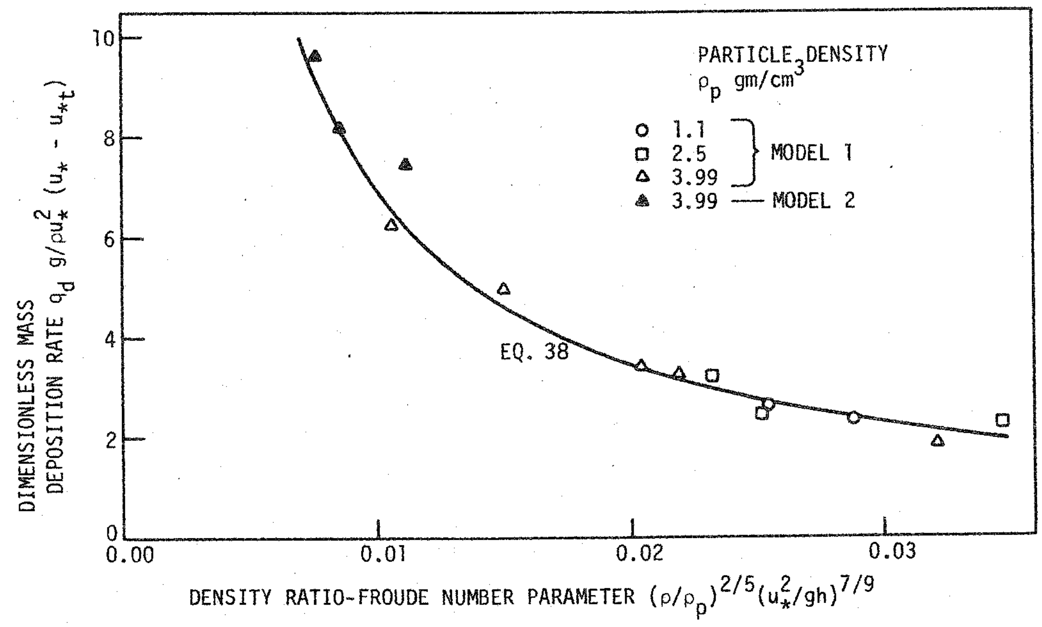

Figure 1. Deposition rate decrease with density ratio and Froude number on an interstate highway model (Iversen, 1980a)

Table I illustrates some characteristics of the experiments performed in water and in air over the past 50 years. In general it can be noted that the densimetric Froude number is easier to satisfy in a wind tunnel and the ordinary Froude number (but not the density ratio) in a water channel. (The densimetric Froude number requirement is buried within the dimensionless deposition rate of Equation 1).

The last two dimensionless factors listed in the table, i.e., $C_D\rho h/\rho_p D_p$ and U^2/U_f^2, as well as the Froude number, are probably important if particle trajectories are to be properly modeled. It is this writer's belief that the individual particle path is not nearly so important to simulate as the way in which material is transported in bulk, if gross snowdrift features are to be simulated. The full-scale speed is predicted by equating full-scale and model values of densimetric Froude number.

CONCLUSIONS

Testing of the snowdrifting caused by small-scale models can be quite useful for studying snowdrifting phenomenon or designing snowdrift control measures. Various investigators have demonstrated over the past 50 years that these types of model experiments can be successfully conducted in wind tunnels, in water channels, or in the free air using natural snow. Qualitative results are more usual than quantitative. If quantitative results are desired or if qualitative results are to be representative in detail, then close attention should be paid to the principles of similitude. The complexity of the similitude problem makes this difficult, but progress is being made.

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LIST OF SYMBOLS

C_D	Drag coefficient
D_p	Particle diameter

g	Gravitational acceleration
h	Characteristic height
L	Characteristic length
q_d	Mass deposition rate
U	Reference wind speed
u_*	Surface friction speed
u_{*t}	Threshold friction speed
U_f	Particle terminal speed
ρ	Fluid density
ρ_p	Particle density
ν	Kinematic viscosity
m	Model (subscript)

Table 1

Reference	Fluid Medium	Modeling Material	ρ_p kg/m^3 Particle Density	D_p μm Particle Diameter	Geometric Scale	U m/s Model Speed	Model Type
Finney (1934,1937, 1939)	air	sawdust & mica	200(?)		12 to 24	4.50 to 13.50	fences, road cuts
Nøkkentved (1940) & Jensen (1959)	air	beechwood sawdust	230		20		fence
Becker (1944)	air	gypsum, peat					
Krentz & Walter (1956)	air	sand	2650	700	20	6.3 to 9.7	fence
Gerdel & Strom (1961)	air	borax	2000	200	10	>4.92	buildings
Tobiasson & Reed (1966)	air	snow	900	150	10		buildings
Sherwood (1967)	air	borax	1730	150	128	6	buildings
Kimura & Yoshisaka (1971)	air	magnesium carbonate	2400	500	100	1.8	buildings
Iversen (1980a)	air	glass	4000	49	120	4 to 7	highway bridge
Anno (1981)	air	activated clay	2500	10	300	7.5	trees
Kind & Murray (1980)	air	expanded polystyrene	160	600	20	4?	fence
Tabler (1980)	air	snow	900	150	30	5	fence
Theakston (1970)	water	sand	2650	120	192	0.2	fence, building
Isyumov (1971)	water	sand	2650	200	200	0.11 to 0.28	building
Calkins (1974)	water	sand	2650	125	200 to 400	0.35 to 0.55	building
Norem (1975)	water	sand	2650	220	100	1.3	road cut
de Krasinski et al. (1975)	water	sand	2650		384	0.15 to 0.27	building
Wuebben (1978)	water	sand	2650	120	50 to 100	0.30 to 0.60	fence
Representative full scale	air	snow	900	150	1	10	

Table 1 (continued)

cm Model Height	U_f/u_{*t} Fall Speed/ Threshold Ratio	U_m^2/gh_m Froude Number	$\rho U_m^2/(\rho_p-p)gh_m$ Densimetric Froude Number	$C_D\rho h_m/\rho_p D_p$ Drag Factor	Square of Ratio of Speed to Terminal Speed	U-m/s Full-scale Speed
5 to 13		16 to 370	0.01 to 0.2			33.5 to 141
5						
4	12.5	2.9 to 68.5	0.01 to 0.03			16.5 to 25.4
ca. 60	5.4	>4	>0.0025	5.6	>16.8	>10.5
170	2.5			300		
3.8	3.9	96.6	0.07	2.35	170	49
5 to 10	10.6	3.3 to 6.6	.0017 to .0034	0.05 to 0.1	0.25	11
4	1.2	41 to 125	.0125 to .038	7.3	224 to 684	21 to 36
4	0.02	143	0.07	9000	965,000	78
7.6	6.6	21	0.16	2	31.5	43
12	2.5	21	0.03	21	331	27.4
2.5	0.76	0.16	0.1	.3750	450	59
3.8	1.8	0.032 to 0.08	0.02 to 0.05	580	19 to 46	33 to 84
9 to 18	0.99	0.07 to 0.34	0.04 to 0.21	6250-12,500	650 to 1600	105 to 233
5	2	3.4	2.1	575	1466	276
2.4 to 8	0.95	0.11 to 1.5	0.07 to 0.93	1950 to 6500	745 to 3000	45 to 127
500	2.5	2	0.0027	900	1800	10