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TECHNICAL NOTES

A SIMPLE DROP TABLE FOR FRACTIONAL GRAVITY —DESIGN AND INSTRUMENTATION

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INTRODUCTION

It is often convenient to conduct experiments in an environment in which gravity is reduced or nearly eliminated Rockets and spacecraft are now available but if a short operating time is sufficient then it is possible to use a falling drop tower or drop table The required distance of fall is readily calculated, showing that an operating time of 0 25 s needs 0 3 m of free fall, easily obtained in a laboratory but longer operating times require at least a stair well and times of many seconds require a tall tower or a mine shaft

For cine observations of the behaviour of growing vapour bubbles relevant to heat transfer rates in boiling useful results have been obtained with drop towers, firstly in a stair well with 0 75 s [1] and later more conveniently in the laboratory with 0 25 s [2] The latter is sketched in Fig 1 and principally discussed below, as the fall of 0 3 m permitted various simplifications in design

DESIGN

The cine camera did not need to fall with the table Instead the camera was focused on infinity and fixed to face downwards into a system of prism and lenses on the table which created an image of the bubble at infinity below the camera (Fig 1) The bubble remained in focus during the fall though the field of view would diminish inconveniently if the fall were much longer

The lights could also be fixed improving their expectation of life They shone downwards onto a mirror mounted at 45 behind the test vessel

Fractional gravity positive or negative could be obtained by applying a constant force upward or downward by a linkage below the table shown in Fig 1 For falls exceeding about 0 3 m such a linkage would be impracticable so a rope or cable with pulley and counterweight would be considered However such a cable must bend so the system would inevitably be elastic hence the release of the table might cause vertical oscillations of moderate frequency with poor damping—highly undesirable for these experiments The linkage was therefore designed instead having high natural frequency and high damping though the force applied by the near vertical link was not of course always truly vertical as it should be However by suitable geometric design the link was arranged to be very close to the vertical through the centroid of

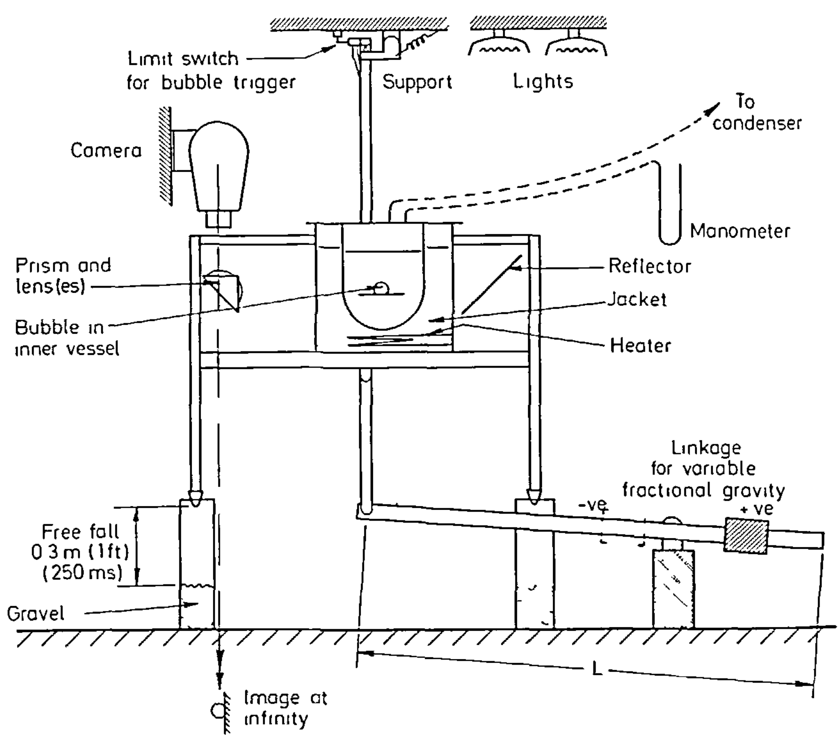

Fig 1 Schematic diagram of a short fall drop table

the table throughout the 0 3 m fall For convenience the fixed pivot was placed two thirds of the way along the main link (of length L mass M_L) so that free fall of that link without counterweight caused the longer end to fall with the local acceleration of gravity g_e With a counterweight of mass m placed (βL) to the right of the fixed pivot the acceleration of the table of mass M_T is a_T where

$$a_T/g = 1-[3\beta/2+(3\beta/2)^2]m/[M_T+M_L/4+(3\beta/2)^2 m]$$

or since M_T is much the largest mass

$$a_T/g \approx 1-[3\beta/2+(3\beta/2)^2]m/M_T$$

so a_T is less than g_e if β is positive and reaches a maximum greater than g_e when β is $-1/3$ Effective gravity fields of $+4\%$ to -1% g_e were therefore obtained by using a counterweight of mass approximately 7% of the mass of the table and varying β from 0 28 to -0 33 Negative gravity could of course be obtained alternatively by inverting the test apparatus but it was often simpler to move the counterweight

OPERATION AND INSTRUMENTATION

Air resistance causes appreciable upward force and various means exist for reducing its effect such as dropping simultaneously an inner test package and a separate outer drag shield [4] Such additional complication was avoided here since the residual effective gravity was measured in any case (as described below) and a compensating downward force could be applied using the linkage Without linkage the amount of residual gravity was nearly constant at about 0 4% g_e implying a nearly constant air resistance of 0 4% of the weight of the table A constant resistance is perhaps surprising but it could arise from inviscid effects since it is known that to impose an acceleration a_s on a massless sphere in infinite inviscid fluid will require a force 0 5 $m_d a_s$ where m_d is the mass of displaced fluid [5] The mass of air effectively displaced by the irregularly shaped table was not clear but might well be of order 0 2% of the mass of the table In addition viscous effects must arise increasing in magnitude as the velocity increases Early experiments with the longer fall suggested that effects of viscous drag and/or wake caused additional resistance roughly proportional to the square of the velocity which became increasingly important after about 0 2 s of fall [1]

Transducers to measure small effective gravity are highly developed for rockets and space craft but a simpler cheaper and very robust fly ball system was preferred for these tests taking advantage of the presence of the cine camera If a body is resting on a spring on the table before release then at the time of release the body effectively loses its weight and the spring expands throwing the body into motion relative to the table The initial relative velocity is $(g_e\delta)^{1/2}$ where δ is the initial spring deflection and by suitable choice of parameters that velocity can be a few mm s^{-1} The body used was a steel ball and its flight was confined to a transparent box which moved with the table The ball was therefore in very nearly free fall since the air resistance due to such low relative velocity is very low indeed If cine photographs then showed the continuing relative motion between ball and table to be a steady velocity then the table was also in free fall Deviations from steady velocity indicated residual effective gravity In the first such design for use by Pike [1] on the longer fall the field of view of the cine camera was split to provide simultaneous photographs of bubble and fly ball the latter having a relative flight path of 75 mm For the 0 25 s drop table a more refined compact design was developed for use by Chandratilleke [3] with a relative flight path of 8 mm occupying almost all of the cine field during special calibration tests The position of the ball could then be measured to 10 μm and the motion could be seen to differ little from a steady acceleration To determine deviations from that steady acceleration would need further refinement of measurement to a few μm There was no point in doing so in these experiments since the bubbles were of order 10 mm diameter and could not be expected to be sensitive to such small deviations from steady acceleration

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THE 'MIRAGE' IN BOILING

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INTRODUCTION

Observation of bubbles in boiling may be much affected by a version of the phenomenon of the mirage or total reflection It is a refraction effect commonly seen when light falls at glancing incidence on a hot flat surface such as a road on a sunny day The light is bent upwards by refraction not reflection though it looks as if reflected from a pool of water the lower part of a distant vehicle cannot be seen the upper part may be seen twice once reasonably undistorted through nearly isothermal air and again inverted in the apparent reflection The cause is well known in outline as the air near the road has a lower refractive index μ (greater light velocity) than the cooler air immediately above it Light therefore follows a path which is curved concave upwards Analogous phenomena of waves travelling in regions with varying wave velocity arise in many fields including propagation of sound in the atmosphere and through geological strata which have