TORONTO 26.9.78

National Research Council Canada Conseil national de recherches Canada

TECHNICAL REPORT 2/74

ASSOCIATE COMMITTEE ON AIR CUSHION TECHNOLOGY

A METHOD OF CONTROLLING "SKIRT-BUZZ" IN LIGHT AIR CUSHION VEHICLES WITH PERIPHERAL-BAG SKIRTS

BY

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(ALSO PUBLISHED AS LTR-ENG-13 BY THE
DIVISION OF MECHANICAL ENGINEERING)

OTTAWA, CANADA

FEBRUARY 1974

PRICE: 50 CENTS

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SUMMARY

The vibrations of peripheral-bag type skirts of light air cushion vehicles were investigated.

A theory is proposed, which enables buzz-frequency to be calculated with reasonable accuracy, and on the basis of which a cure for the vibrations is proposed. The successful application of this cure to a half-scale model and two actual vehicles is described.

1. Introduction

Investigation of the question of skirt-vibration of Air Cushion Vehicles was cited at the first meeting of the Associate Committee of Air Cushion Technology as being of urgent importance.

The skirt of an ACV is a membrane structure inflated by the internal pressure of the "lift" airflow, and any pulsations in this airflow can lead to vibration of the skirt. This vibration can vary in frequency and severity, and can result in vertical oscillation of the whole vehicle sufficient to damage the structure and incapacitate the crew.

This report describes an investigation into the skirt-vibration in a light ACV, experiments on a half-scale model, and a resulting treatment which cured the vibration on both model and vehicle.

2. Definition

Many different types of vibration are observed in ACV skirts, and are frequently referred to collectively as "Tramping". The present report refers specifically to a relatively high-frequency vibration of the skirt only, in the range of 10 Hz (cycles per second) and above. It is very frequently met with in light ACVs, and can cause severe skirt wear. It does not involve appreciable vertical oscillation of the hard hull of the vehicle. This type of vibration is referred to here as "Skirt-Buzz", to distinguish it from lower frequency oscillations affecting the whole vehicle, which are described as "Jumping".

3. Description of Vehicle 1 and Model

The vehicle investigated was a light (two-seat) ACV, kindly lent to NRC for these experiments by its builder, Mr. R. Wade, whose assistance in the investigation was greatly appreciated. It is shown in Fig. 1. The model was an exact ½-scale model of the airduct and skirt system, and is shown in Fig. 2. It was built of ¼" plywood, with a skirt made of .0035" transparent plastic membrane.

In the actual vehicle, lift air was supplied by a 10-blade axial fan driven by an 18 HP two-stroke engine at 4000/4500 RPM. In the model it was supplied via a 6" dia. flexible plastic pipe from a centrifugal blower driven by a 1½ HP electric motor, and a metering orifice on the blower inlet enabled the flow quantity to be measured.

4. Experimental Procedure

The procedure was the same for both vehicle and model.

The total vehicle weight was first measured. The vehicle was then placed on hard smooth ground (asphalt or plywood on concrete) and hovered, with the engine of the vehicle at full throttle, or the blower of the model at constant rpm. Readings of fan delivery total pressure (actual vehicle only), skirt pressure, cushion pressure, and airflow (model only) were then taken, for the empty vehicle and with successive increments of load of 50 lbs, up to 200 lbs (vehicle) and 350 lbs (model).

The skirt buzz was examined visually at each load in the light of a Strobotac lamp, and its frequency read off the lamp setting scale. These observations are shown in Figs. 3 and 4. Without at this stage attempting to correlate the buzz frequencies and model scale factor, it is seen that the behaviour of the actual vehicle and the model are comparable.

After the theoretical consideration of the results described in a later section, the proposed buzz-control device was applied to the model, and subsequently to the actual vehicle, and the foregoing experiments repeated. In both cases all the measured quantities remained constant, except that the buzz was virtually eliminated. A small, very high frequency vibration could be detected under some conditions, but it was so small that it seems possible to neglect it.

The same exercise has since been carried out on a second full-size vehicle, with similarly positive results.

5. Theoretical Analysis of the phenomenon

By observation of the vibrating skirt in stroboscopic light, it appeared that it was vibrating in the simple second-order mode shown in Fig. 5. It seemed reasonable to compare this with the vibration of a stretched string, as described in a standard Physics textbook (e.g. Ref. 1). A simple theory was therefore proposed, comparing a two-dimensional element of the "bag" skirt to such a string. It was realized that the simulation is not exact, as the curved ends of the skirt will introduce end constraints, and indeed some longitudinal phase-waves were observed, but the concept seemed sufficiently true for practical purposes.

The standard formula describing the vibration of a stretched string (Ref. 1) is:-

$$N = \frac{n}{2L}\sqrt{\frac{F}{m} g_o}$$

where

N = Frequency - Hz (cycles/sec)
L = Length - feet
F = Tensile force in string - lbf
m = Wt. per unit length of string - lbm/ft
$g_o = 32.2 \cdot \frac{\text{lbm}\times\text{ft}}{\text{lbf}\times\text{sec}^2}$
n = Vibration Order (1,2,3, etc)

The detailed calculation is set out in Appendix 1. From this, the calculated frequencies were obtained, and are as set out below. It is seen that the calculation gives frequencies which vary a little from those measured experimentally, but the correspondance is close enough to be useful in practice, and the errors may reasonably be explained by the three-dimensionality and end-constraints of the real case, as discussed above.

Table of Calculated and Observed Buzz Frequencies

Configuration	Model		Vehicle 1		Vehicle 2	
Load	150 lbs	300 lbs	0 lbs	150 lbs	0 lbs	125 lbs
Calc. N	74 Hz	92.3	34	36.5	18.6	19.6
Measured N	72 Hz	92.5	38	42	18.4	22.5
Calc/Meas. N	1.03	1.00	.90	.87	1.01	.87

6. Device for Controlling Skirt-Buzz

It appeared clear from these experiments that the mode of vibration normally encountered with a simple peripheral bag type of skirt is a second-order transverse mode. It seemed therefore that if a damping mass were attached to the element near an antinode (point of maximum amplitude) it would absorb enough energy to damp out the vibration of the system. It should not be placed exactly at an antinode, as this could break the mode into a half wavelength vibration at twice the original frequency, and still of appreciable amplitude. The proposal was therefore to place a mass a short distance from the antinode, and further to split it into two smaller mases a short distance apart, to render the device still less likely to set up a strong high-frequency mode.

In practical terms, two staggered rows of small lead weights were attached to the model skirt, in small pockets, Fig. 6.

After successful tests of the model, a similar array of weights, roughly twice the model size, were put in pockets on the actual vehicle, again with successful results.

On the second vehicle, the small pieces of sheet lead were replaced by packets of lead shot. The reason for this was simply to keep the weights, known as "Buzz-Dingers", flexible and free from sharp corners, so that they would not wear the skirt locally.

The exact weights and arrays were decided on quite arbitrarily. Since they worked satisfactorily, for a total weight penalty of less than 2 lbs for the first vehicle and about 3 lbs for the second vehicle, which had a much heavier skirt material, no effort has been made to reduce them. This is however open to experiment. When the Vehicle 1 was hovered off the asphalt and onto short grass during the experiments, it was noticed that the buzz stopped abruptly as soon as about one-third of the skirt was onto the grass. This is in fact a normal phenomenon with vehicles of this type.

It is postulated that when hovering over grass, the skirt is still suspended above the hard ground but is still contacted by a great number of springy grass leaves, which give sufficient transverse damping to the skirt undersurface to reduce the vibration greatly, or completely stop it.

7. Conclusions

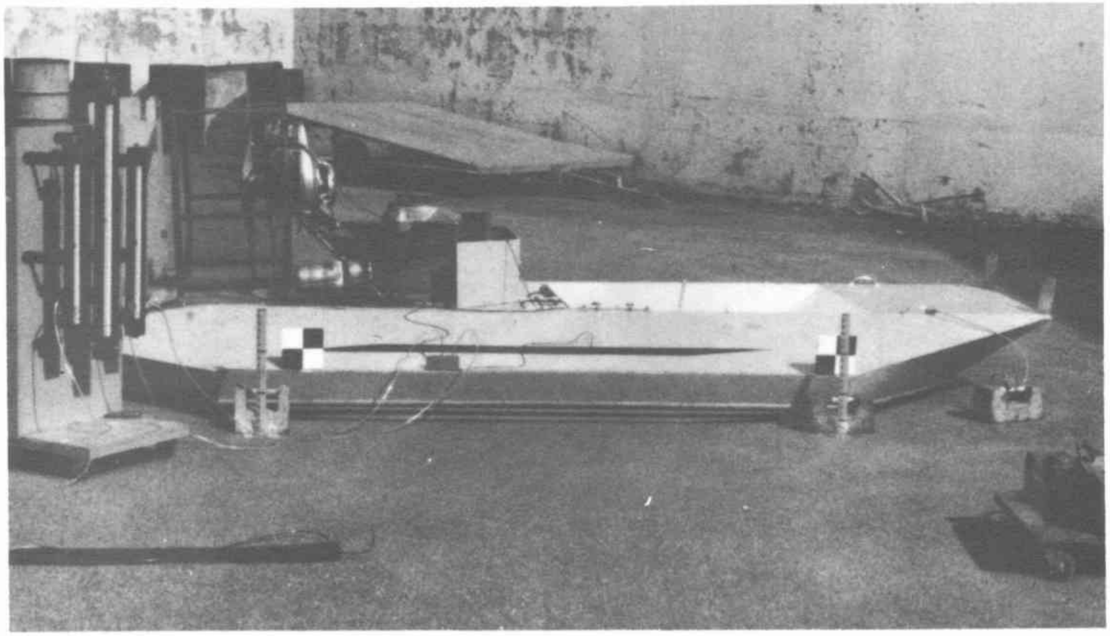
A theory has been advanced, suggesting that the buzz of a simple peripheral bag skirt on an ACV may be treated as the "stretched-string" vibration of a two-dimensional element of the skirt. Calculations are presented showing the application in practical cases.

Based on this theory, a device, the Buzz-Dinger array, is described. It is shown that in the cases tested this device did substantially eliminate skirt buzz. It was also concluded, from observations during the experiments, that the absence of buzz over grass is probably due to the damping of the skirt vibration by the transverse friction of multitudes of grass leaves.

The technique described in this report is considered proprietary, and should not be employed without reference to the National Research Council of Canada.

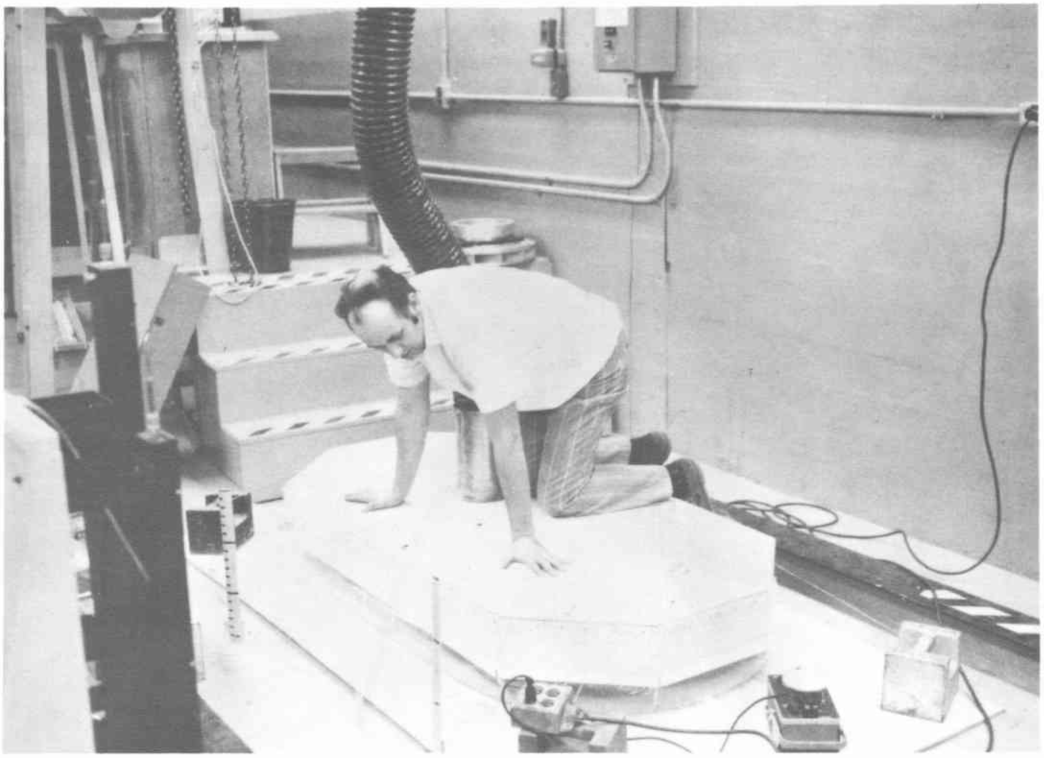
8. Reference

SMITH, C.J. "Intermediate Physics" 2nd Edition, 1938. p.543. Published by Arnold Press.



VEHICLE 1 READY FOR TEST ON ASPHALT SURFACE.

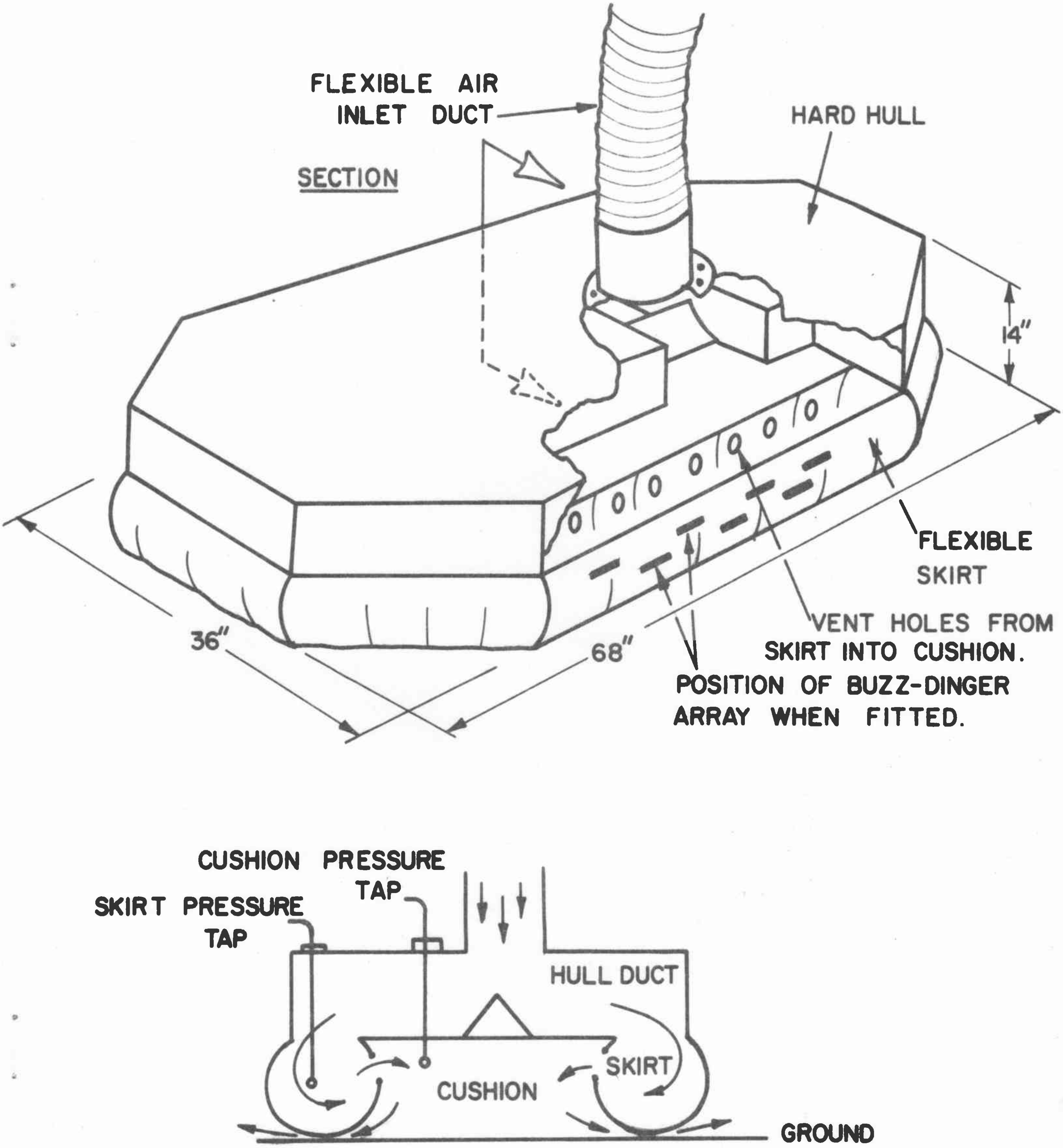
a.



HALF-SCALE MODEL HOVERING ON SMOOTH PLYWOOD SURFACE.

b.

FIG. 1



MODEL SKIRT AND AIRDUCTS

FIG. 2

SKIRT-BUZZ EXPERIMENT
VEHICLE 1 ON ASPHALT

VEHICLE TOTAL WEIGHT = 542 lbs.
SKIRT WEIGHT = .046 lbs/ft.^{2}

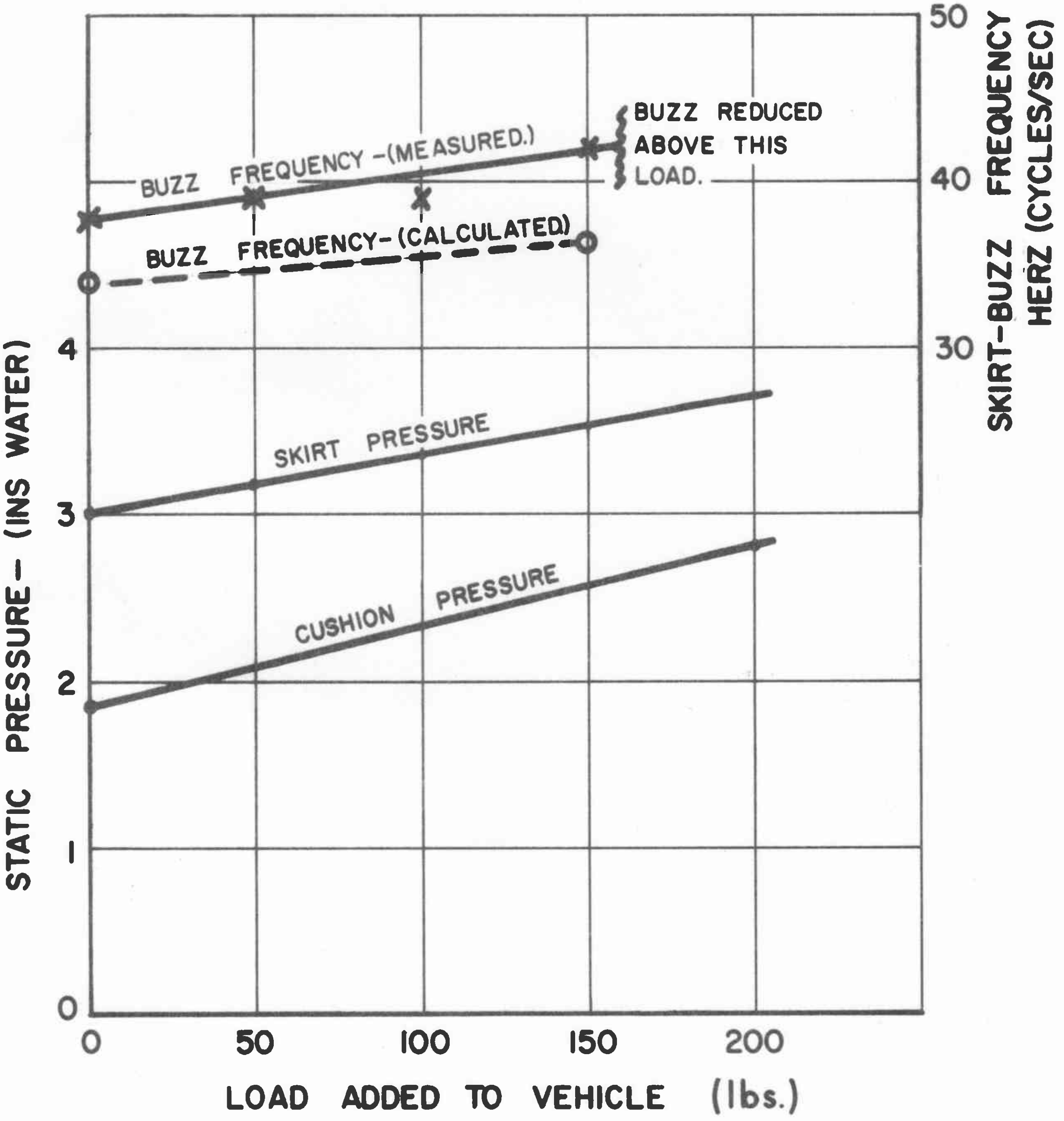


FIG. 3

SKIRT-BUZZ EXPERIMENT
HALF-SCALE MODEL ON PLYWOOD

VEHICLE TOTAL WEIGHT =50 lbs.
SKIRT WEIGHT =.02 lbs./ft.^{2}

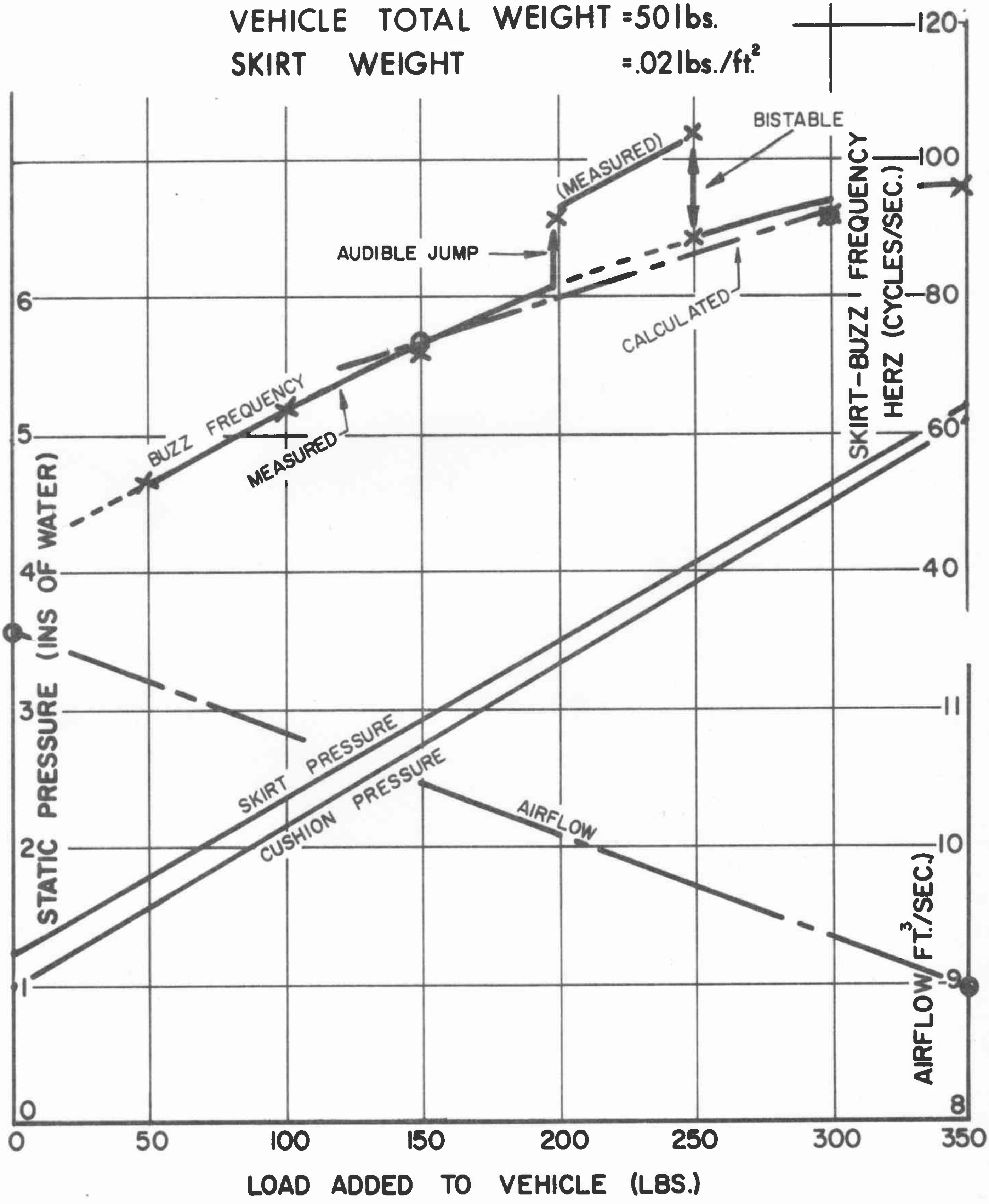
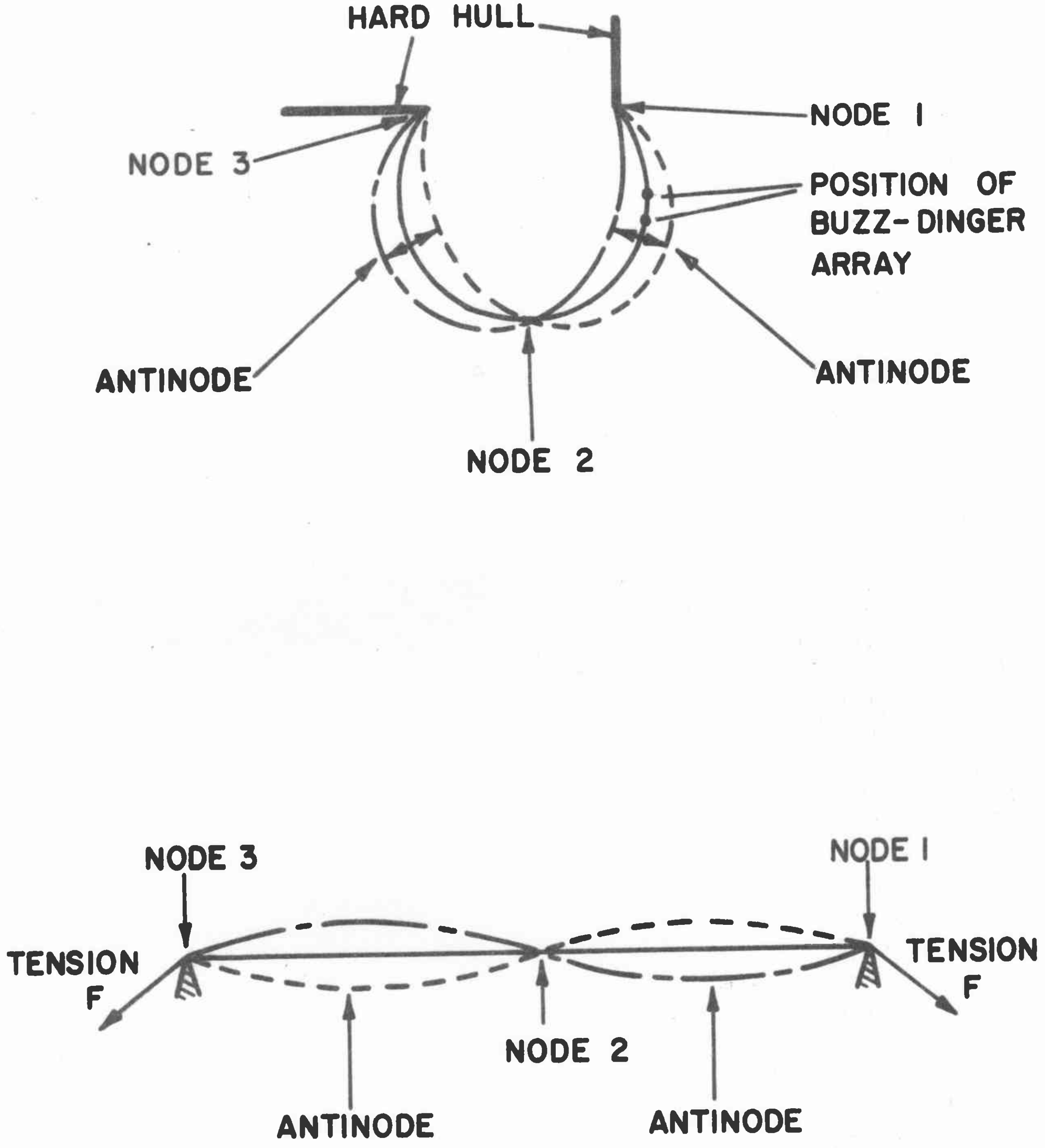
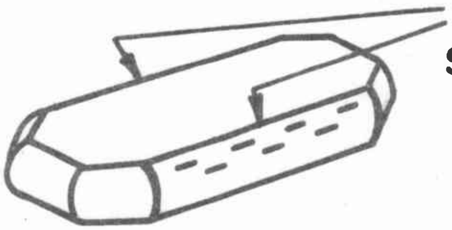


FIG. 4

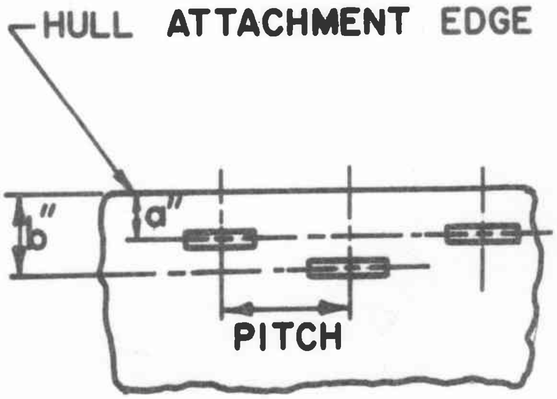


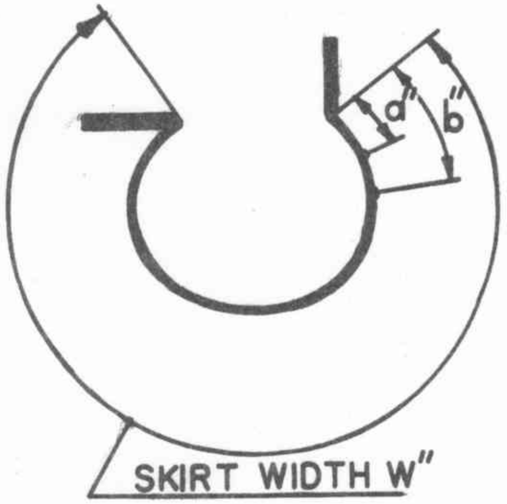
VIBRATION MODES IN FLEXIBLE SKIRT AND STRETCHED STRING.

FIG. 5



ARRAYS PUT ALONG SIDES OF SKIRT ONLY. ENDS LEFT UNTREATED.





	W″	a″	b″	PITCH″	Nº/SIDE	WEIGHT lb EACH	WEIGHT lb TOTAL	SIZE″
MODEL	14	2	3	4	11	.07	1.55	$2 \times \frac{1}{4} \times \frac{1}{16}$
VEHICLE 1	28	5	7	6	15	.13	3.9	$3 \times \frac{3}{8} \times \frac{1}{8}$
VEHICLE 2	30	4	6	6	15	.18	5.6	LEAD SHOT

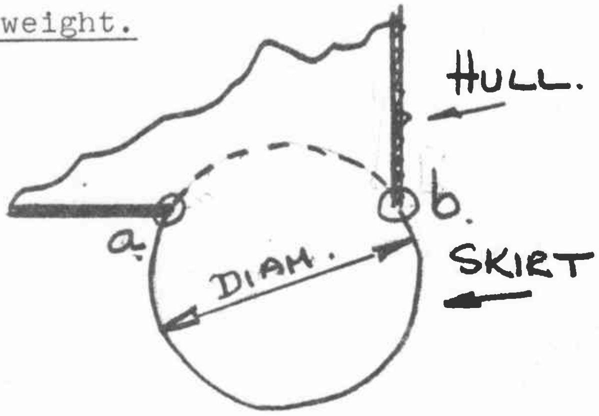
DETAIL OF BUZZ-DINGER ARRAYS.

FIG. 6

Appendix 1. Calculation of Buzz Frequency

Model at 150 lbs added weight.

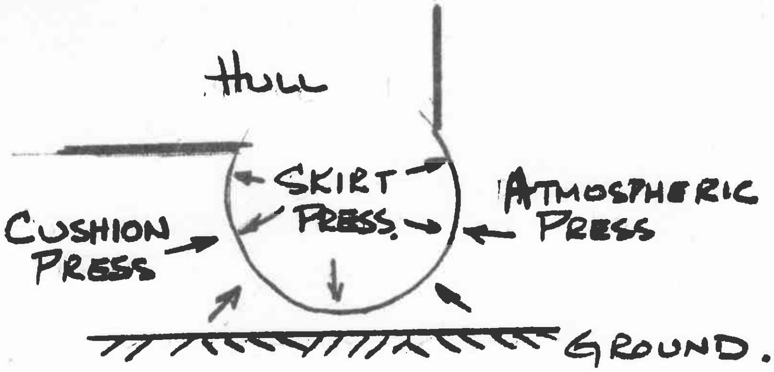
Skirt Profile



Skirt length a - b = 14".

It is estimated that this forms approximately 2/3 of a circular section, of about .6 ft diameter.

In a 1 ft long element (1 ft perpendicular to the plane of the diagram) we will consider the tensile load.



As a simplification, we consider the skirt to be exposed to SKIRT PRESSURE inside, and ATMOSPHERIC PRESSURE outside. We neglect the effect of CUSHION PRESSURE on part of the skirt. Results appear to justify this assumption.

$\therefore$ Pressure difference across skirt = Skirt Pressure
= 3.0" H_2O = 15.6 lbs/ft^2.

$\therefore$ In 1.0 ft long element,
Force on diameter = 15.6 × 1 × .6 = 9.3 lbs.

$\therefore$ Tensile load at ends of element = 9.3/2 = 4.65 lbs/end.

Material weight (measured on sample) = .02 lbs/ft^2, which equals the weight/foot of the 2-dimensional element 1 ft wide.

In the observed mode of vibration (in all cases tested) the skirt element length equals one wavelength.

Wavelength = 14" = 1.17 ft.

Substituting in the equation for string frequency;-

$$N = \frac{1}{1.17} \times \sqrt{\frac{4.65}{.02} \times 32.2} = 74 \text{ Herz.}$$

Observed frequency (from Strobotac) = 72 Herz.