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TECHNICAL REPORT 3/77

ASSOCIATE COMMITTEE ON AIR CUSHION TECHNOLOGY

# THE CASPAR ACV RESEARCH PROJECT
# REPORT NO. 5
# THE MULTICELL SKIRT WITH A CELL-SEALED PERIMETER AND CENTRAL PRESSURISED CAVITY
## (THE "HOLLOW WALL AND PRESSURISED CAVITY" CONCEPT) IN OVERLAND OPERATION

BY

H.S. FOWLER

OTTAWA, CANADA

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CONTENTS


| | | Page |
|---|---|---|
| | SUMMARY | ii |
| 1. | INTRODUCTION | 1 |
| 2. | REASONS FOR DEVELOPMENT OF THE SYSTEM | 1 |
| 3. | THEORETICAL EXAMINATION OF THE HOLLOW-WALL SYSTEM | 2 |
| | a. General | 2 |
| | b. The Basic Multicell Geometry | 3 |
| | c. The Modified Hollow-Wall Cell | 4 |
| 4. | PRACTICAL STUDIES OF THE HOLLOW-WALL SYSTEM | 6 |
| 5. | CONCLUSIONS | 10 |
| 6. | REFERENCES | 10 |

## SUMMARY

The report discusses the "Hollow Wall and Pressurised Cavity" skirt, which is a particular development of the general multicell skirt which was discussed in the previous report (No. 4) of this series.

The skirt arrangement is considered from a theoretical point of view, and it is shown that its geometry renders it liable to structural instability under the distribution of air pressures and stresses with which it is designed to operate.

A model and three vehicles incorporating this skirt design are described, and it is shown that all exhibit to some degree the phenomena to be expected from the foregoing theoretical discussion.

It is concluded that the system as at present understood appears to embody certain basic defects of cell structural instability, and unless these can be avoided by a fundamental redesign of the system, it does not appear to be practically useful.

CASPAR REPORT NO. 5

# THE MULTICELL SKIRT WITH A CELL-SEALED PERIMETER AND CENTRAL PRESSURISED CAVITY

(The "Hollow Wall and Pressurised Cavity" Concept)

OVERLAND OPERATION

## 1. INTRODUCTION

The basic "Multicell" air cushion vehicle skirt system was developed by Bertin in France, and is discussed at length in Ref. 1. In the simplest form, the skirt assembly consists of a group of inflated truncated-cone "cells" under the hull of the vehicle. The total lift of this arrangement is however only equal to (cell-pressure x cell area) and as the maximum area of circular cells which can be placed under a rectangular hull is only roughly 3/4 of the hull area, this total lift is less than could be desired.

The lift has often been increased by surrounding this group of cells by a "peripheral skirt" enclosing the whole hull area. This increases the available lift, but at the price of complication, a fragile peripheral skirt which is prone to damage, and lack of accessibility to the cells for field maintenance.

In the attempt to gain the advantage of a footprint area equal to vehicle hull area without using a peripheral skirt, one possible arrangement is a peripheral row of close-packed cells, enclosing a pressurised central cavity which is sealed by the close contact between the cell sides.

This arrangement has been known for many years, and an example was described in 1971, in Ref. 2 under the name "Pericell".

Most attempts to use this arrangement have been abandoned without explanation. It is therefore of interest to examine the arrangement, to see why it has not yet been successful, and if it could be made to succeed.

This study is concerned with overland operation only, and does not cover the marine case.

To avoid trade names, the arrangement is here called the "Hollow Wall" skirt.

## 2. REASONS FOR DEVELOPMENT OF THE SYSTEM

The Hollow Wall system lies in the no-man's-land between the Finger/Segment systems and the more usual Multicell arrangements, and can be approached from either side.

Reasoning from the Finger/Segment skirts, this Hollow Wall arrangement

in effect modifies the segment elements from virtual half-cells to complete cells, and alters the air feed arrangement, to provide a skirt much stiffer in roll, pitch, and heave. It also becomes more prone to heave oscillation.

On the other hand, the Hollow Wall skirt may be regarded as a development of the standard Bertin Multicell, in which small cells are grouped closely as a wall round the periphery of the hull, retaining cushion pressure in the cavity so enclosed simply by close contact between their sides. This gets rid of the structurally weak peripheral skirt of the Bertin arrangement without losing effective cushion area, could reduce the weight and cost of skirt material, and can reduce the difficulty of replacing damaged cells in the field. On the debit side, it involves some loss of structural stability of the cells.

## 3. THEORETICAL EXAMINATION OF THE "HOLLOW WALL" SYSTEM

### a. General

As was discussed briefly in Ref. 1, development of Multicell skirts in Canada has raised interest in versions of the Hollow Wall system. Difficulties encountered with this system on a full-size vehicle led to a discussion of the theory of such skirts, and some model experiments, which will now be described.

Basically, the "Hollow Wall" system consists of a row of tightly spaced separate multicells round the periphery of the vehicle, retaining a high pressure cushion of air in the cavity thus enclosed. This cavity can be fed separately, or by inwards air leakage under the hems of the cells. The vehicle thus has air cushion support under its whole area. The scheme is shown in Fig. 1.

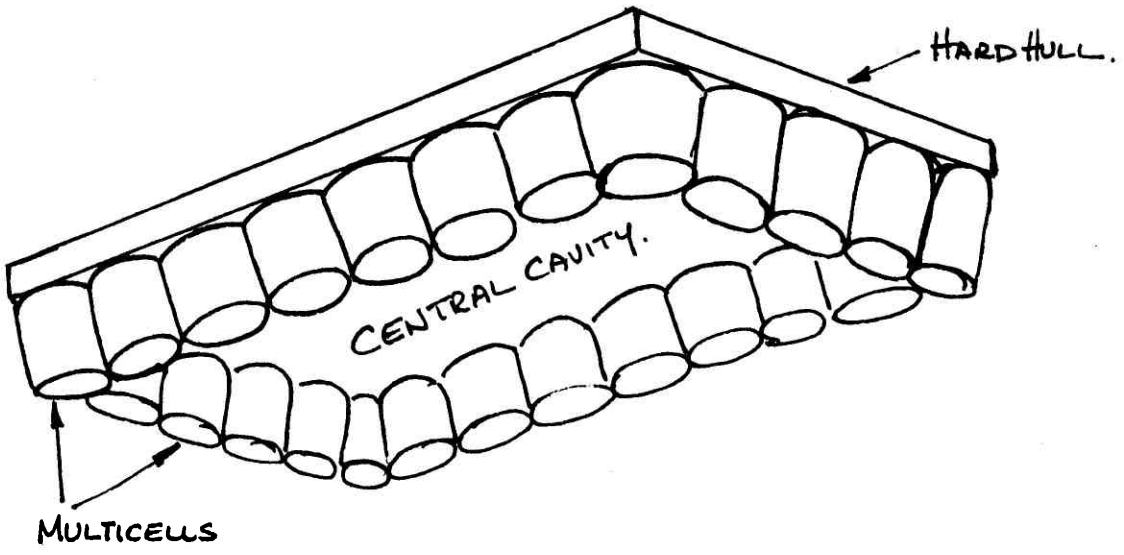



FIGURE 1 VIEW OF "HOLLOW WALL" SKIRT CONCEPT FROM BELOW

It will be appreciated that an essential feature of this system is that the adjacent cells butt up against each other firmly when inflated in order to provide an effectively continuous seal round the periphery of the vehicle, to retain the pressurised air in the central cavity. This involves a significant departure from the geometry of the simple multicell, as found in the original Bertin principle. This point will now be examined closely.

b. The Basic Multicell Geometry

In Ref. 1 the simple multicell unit is discussed at some length, as follows:

The cell on which the system is built is a truncated cone of light flexible material, with an air feed in the top (large diameter) and with the open bottom (smaller diameter) hovering a small distance (the "hovergap") above the terrain (Fig. 2).

The air within the cell is quasi-stagnant, at "cushion pressure", while it escapes through the hovergap with a speed corresponding

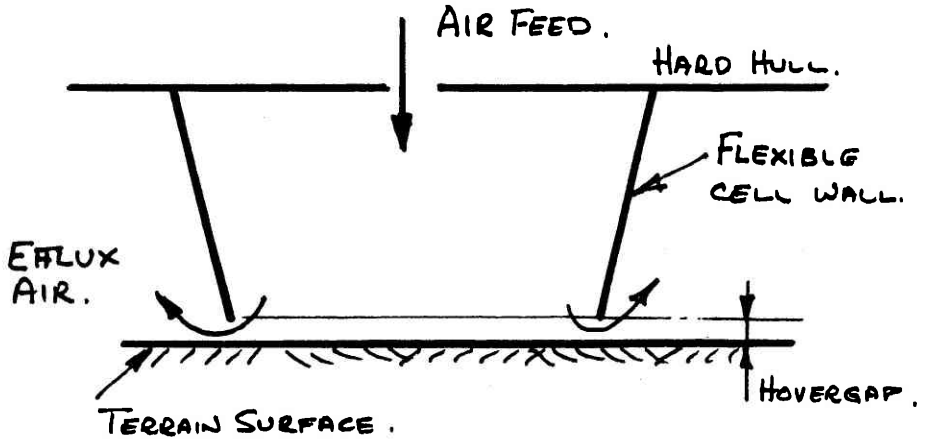



FIGURE 2

to a dynamic pressure equal to the pressure difference between cushion pressure and atmospheric pressure. The cell is maintained stiffly developed by this same pressure difference, exerting a peripheral (hoop) tension in the cell wall; and because the bottom diameter of the cell is smaller than the top, a vertical force is exerted downwards on the inside of the cell wall to keep it developed vertically.

These stresses are diagrammed below, in Fig. 3.

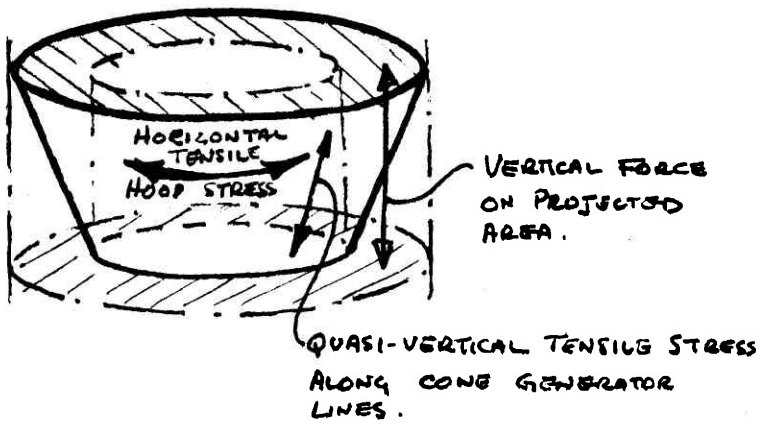



FIGURE 3 STRESS SYSTEM IN CELL (SIMPLIFIED).

Between these two stresses, the cone becomes a stable inflated shell structure.

When the cells are dragged over rough ground, a shear is set up between the lower hem (exposed to ground friction) and the upper hem, (exposed to vehicle thrust), and there is a tendency for the cone to buckle. There is a critical cone angle (which controls the vertical stress) above which for a given inflation pressure and frictional shear force the cone will remain stable, and below which it will buckle (Fig. 4). Normal practise, supported by plenty of field tests, suggests 10° or 12° as the minimum total included cone angle for reasonable cell stability. It is essential to note that such a cell will always tend to assume a conical form, with circular horizontal cross-sections, when inflated.

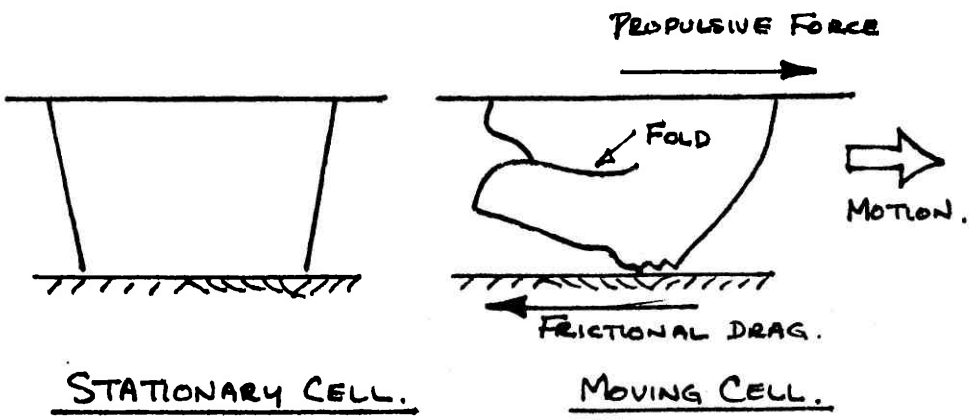



FIGURE 4 FOLDING DUE TO MOTION.

c. The Modified "Hollow Wall" Cell

When the cell is employed in a group of neighbouring but not

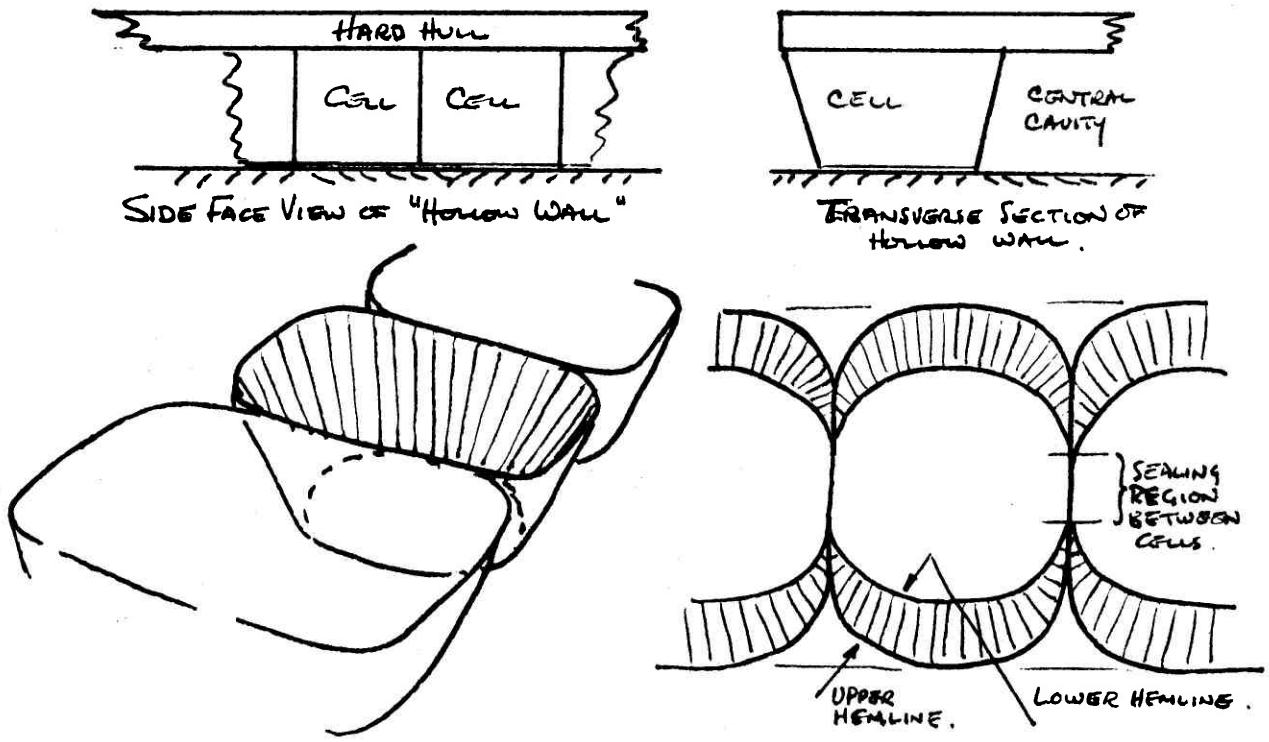
contacting units, the basic truncated-conical geometry can be used. However, when neighbouring cells are required to contact tightly and form a complete seal from top to bottom between them, this simple geometry has to be modified.

Essentially, the requirement is that the "sides" of the cell are no longer conical, but are vertical so that the "sides" of adjacent cells meet. The "inner" and "outer" ends of the cell retain the sloping "conical" geometry, in order to retain the vertical stability of the cell. But since this conical form is only local, the overall vertical structural stability of the cell might be expected to suffer. This is indeed found to be the case.

The modified form of the cell is shown in Fig. 5, and the areas in which vertical force has disappeared are immediately obvious.

It is clear from the lower right sketch in Fig. 5 that in the inter-cell sealing region at the "sides" of the cell, the cell has vertical sides, no projected vertical area, and therefore no vertical stabilising force.

The above treatment contains a number of simplifying assumptions, of which the most drastic is that the cell has a uniform differential pressure between inner and outer surfaces acting over its




IDEALLISED FORM OF "HOLLOW WALL" MULTICELL SKIRT.

FIGURE 5

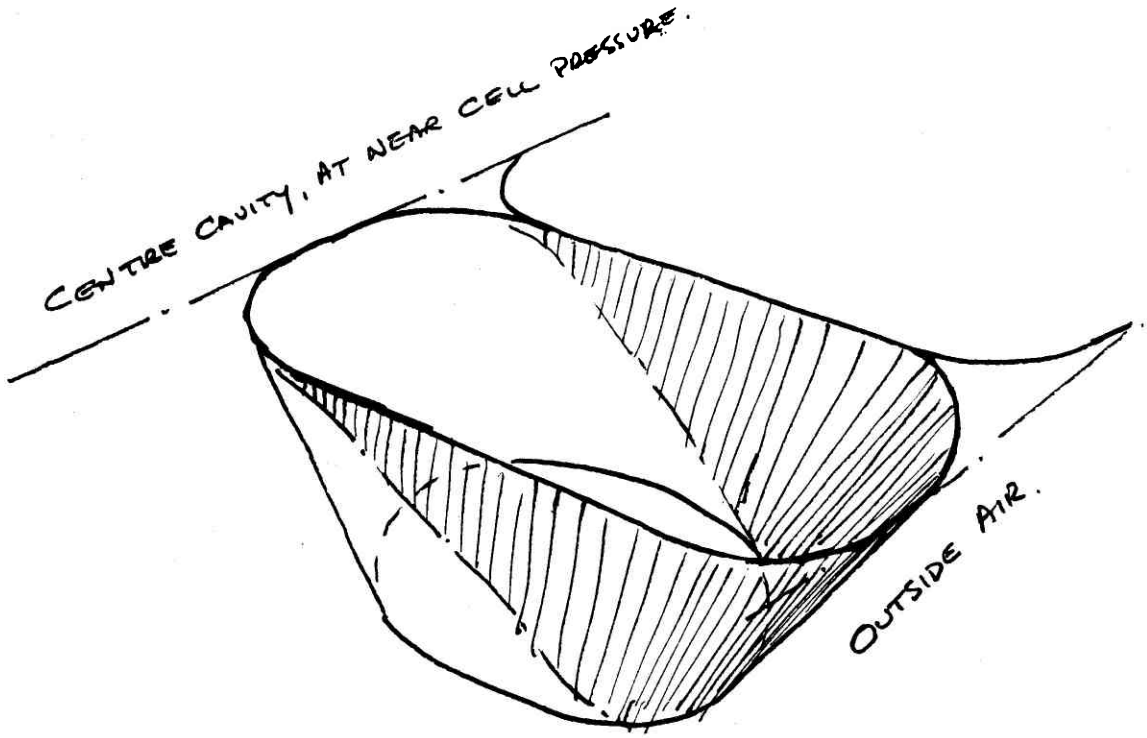
whole area. This is completely contradicted by the essential feature of the Hollow Wall arrangement, that the inner cavity is maintained at something approaching cell pressure, to contribute a large part of the lift of the vehicle. Hence, while the pressure difference across the outer half of the cell wall is cell pressure/atmosphere, across the inner half of the wall the differential pressure is only cell pressure/cavity pressure, which is small or zero. This clearly has drastic effects on the cell hoop stress, and further reduces the cell's structural stability. In fact the only parts of the cell left stressed are as shown in Fig. 6, while the remainder of the cell hangs limp. The geometry of the cell wall is not well equipped to withstand this new stress distribution, and in practise the cell then assumes a somewhat altered shape, and tends to become unstable structurally. As Fig. 6 shows, it effectively assumes a form comparable to an element of a finger or segment skirt, but arranged at far from the optimum angles for such a unit.

In practise, owing to the drastic reduction of hoop stress and elimination of much of the vertical development force, the outer face of the cell tends to balloon out, still further reducing the horizontal projected area of the now almost non-existant cone and hence reducing the vertical developing force yet more. The cell sides, too, tend to pull in, thus permitting considerable leakage between cells. Finally, sideways shear due to motion over rough ground buckles the cell with extreme ease, causing an early onset of the distortion shown in Fig. 4. When this occurs, lowering the vehicle off hover crumples the cells in the buckled form. The next inflation tends simply to blow off sideways through the buckled sides, and the vehicle is unable to rise.

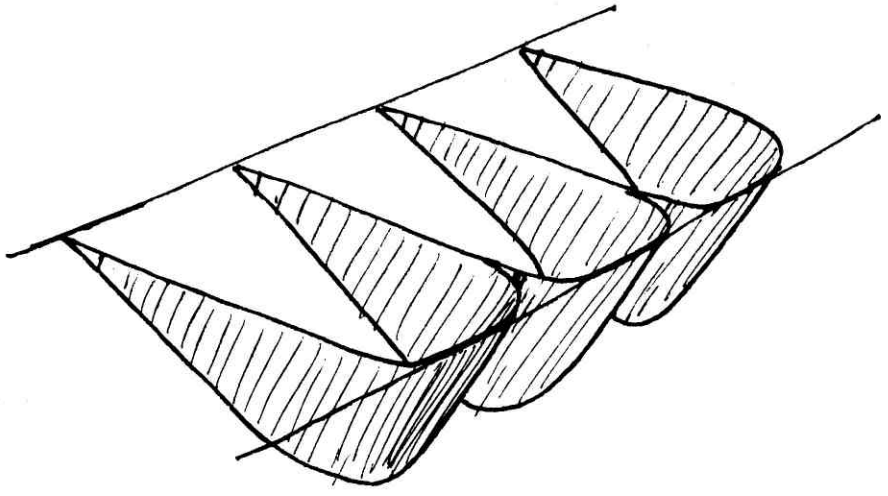
## 4. PRACTICAL STUDIES OF THE "HOLLOW WALL" SYSTEM

The system has been studied in a model skirt-box, with 0.4 metre width cells, and on three full-scale vehicles, a 20000 N. (2½ ton) raft, an A.C. Assist trailer, and a 1,000,000 N. (100 ton) raft. Similar phenomena occurred on all these, although it was not clearly recognised until the largest vehicle showed the phenomenon with startling clarity. Examination of photographs and data relating to the earlier vehicles showed the same behaviour in a reduced scale, and the 1/3 scale model of the large vehicle duplicated the vehicle behaviour perfectly. Smaller scale models had not shown the same thing clearly, possibly because of the relative stiffness of small model skirts.

An experimental program showed that when the cavity pressure was less than 0.7 of the cell pressure, the effect of lack of pressure difference across the inner cell wall was greatly reduced, and the cells did not show the major instability here described. This is held to explain the moderately acceptable behaviour of a further (8500 N.) vehicle, where the cavity pressure of a hollow wall arrangement varied, but was less than 0.7 of the cell pressure.




SHADED AREA SHOWS THAT PART OF CELL STILL STRESSED UNDER "HOLLOW WALL & PRESSURISED CAVITY" CONDITION.



SEGMENT SKIRT — FOR COMPARISON.

FIGURE 6 STRESSED AREAS IN HOLLOW WALL AND SEGMENT SKIRTS

In the as-designed condition, the model and all the vehicles showed the same characteristics:

a. There was appreciable leakage between cells, up the full height of the cell. It is particularly difficult to avoid this at the top of the cell, due to the mechanics of hull attachment, and at the bottom, due to the distortion of the hem referred to above. These leaks were sufficient to drop cavity pressure to perhaps 75% of cell pressure, but even so the inner wall of the cell was not developed, and indeed often hung idly. While it may be argued that such a leak is desirable and can be used to drop the cavity pressure in order to stabilise the inner cell wall, this is very doubtful. For one thing, sufficient drop to stabilise the cell would reduce the lift of the cavity to an unacceptably low value, and for another, the leak is not controllable but varies greatly with forward movement of the vehicle, and general cell development.

   Between-cell leakage could be eliminated either by positively fixing adjacent cells together down their common face by bolting or glueing, or by putting a small web of skirt material between them in the same place. Either of these arrangements would greatly reduce the flexibility of the skirt as a cushion seal in its ability to seal round obstructions. The structural weakness of the peripheral skirt would also be reintroduced, at the joints between cells, or between cell and web.

b. The outer face of the cells bulged out to a considerable extent, and reduced the vertical stabilising downward force on the cell. This was due largely to the relaxation of hoop tension in the cell resulting from the unstressed condition of the inner half of the wall. Fig. 7 shows this effect. The bulge reached values of around 15% of the cell height.

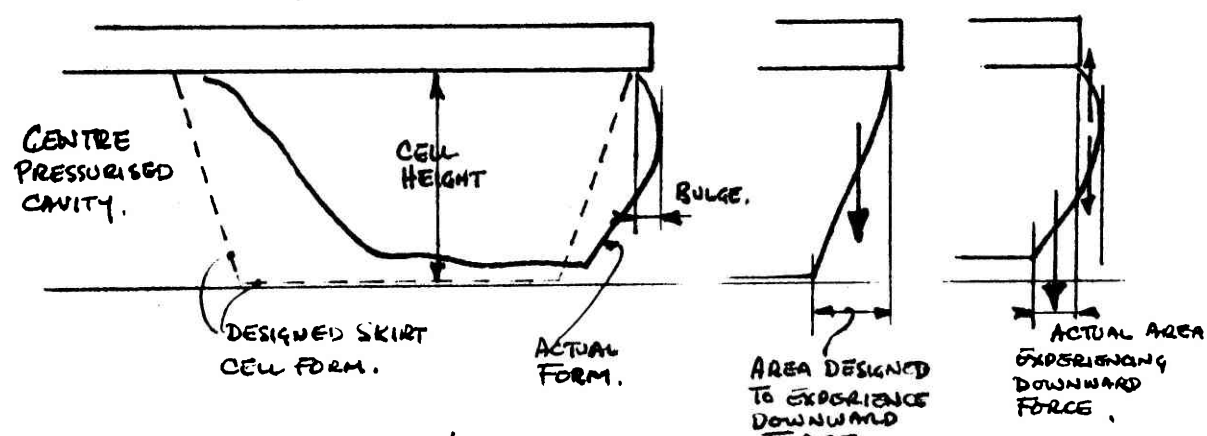



FIGURE 7 EFFECT OF 'BULGE' ON SKIRT FORCES.

This effect can be to a fair extent counteracted by putting "tucks" into the skirt, and reducing the bottom hemline circumference by as much as 22%, which certainly reduces the bulge but at the price of 10% reduced hoverheight and increased leakage between cells due to constricting the bottom width of each cell.

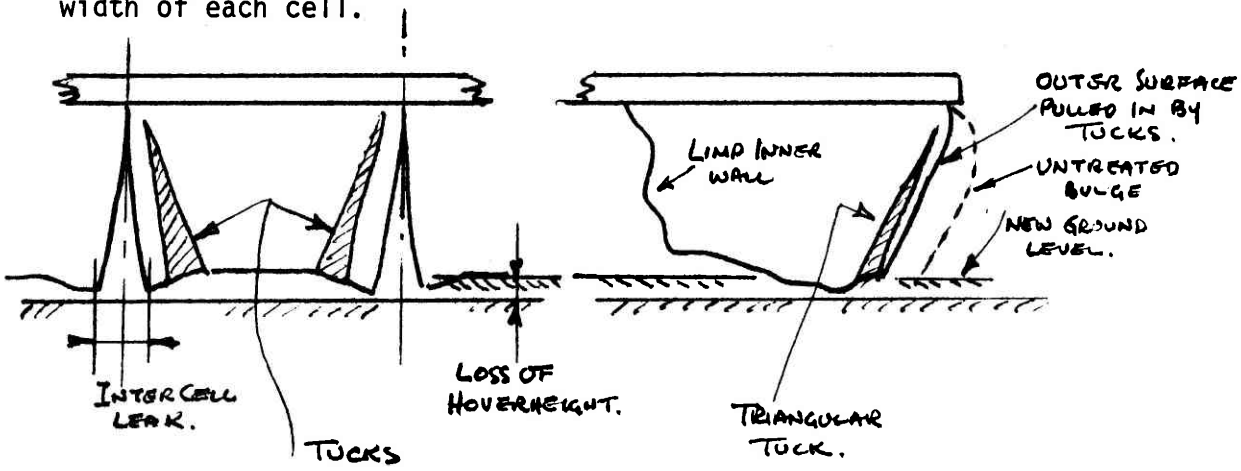



FIGURE 8 TUCKS IN THE CELL.

If the cavity pressure can be maintained reliably at less than 0.7 of the cell pressure, the cell structural stability is improved.

It appears that such a cavity pressure can only be maintained by blowing off air from it in a controlled manner, which is wasteful of lift power. The use of natural leakage between the peripheral cells is not satisfactory, since it varies so much during operation that a consistent controlled leak is unlikely to be obtainable.

c. Sideways buckling of the cells during vehicle movement, and even while stationary, was clearly and continually observed in the AC trailer and the largest vehicle, despite the range of cell height/diameter ratios, (1/2.5 on the trailer and 1/1.5 on the large vehicle).

This buckling was most severe in the taller skirt (on the largest vehicle) and occurred repeatedly during stationary lift-and-drop cycles. After the "tuck" modification it was cured in the stationary mode, but still occurred to an unacceptable extent during travel over flat gravel terrain.

Outer face bulge could be reduced by increasing the "cone angle", particularly of the inner wall of the cell, to a very great extent (45° to vertical or more)

so that the tension direction in the inner wall corresponded to the inner edge of a finger or segment, and so that the outer wall had enough projected vertical area to generate sufficient vertical downward force to ensure firm vertical development of the cell.

However, the increase of cone-angle over parts of the cell would make it much more prone to snagging on land, or scooping on water.

These approaches might reduce the buckling tendency, but experience with the "tuck" modification which does in fact achieve suggestion (c) above, at least in the outer face, suggests that this approach is only partly effective, and has severe disadvantages.

It is believed that a somewhat similar approach was among those tried on an amphibious craft in the U.S.A. in the mid 1970's. In the marine environment it may have been more successful than the present note suggests, since this note is concerned entirely with overland operation. However, no reports on the results of this development have yet come to hand.

In summary, so far no effective remedy for these troubles has been discovered, and the phenomena seem to be fundamental to the "Hollow Wall and Pressurised Inner Cavity" concept.

## 5. CONCLUSIONS

The "Hollow Wall and Pressurised Inner Cavity" ACV skirt concept has been discussed theoretically, and practical experience has been shown to bear out the theoretical analysis. Small scale models, however, do not always fully duplicate full-scale behaviour.

The system as at present understood appears to embody certain basic defects of cell structural instability.

Unless these defects can be avoided by a fundamental redesign of the system, it does not appear to be practically useful.

## 6. REFERENCES

1. Fowler, H.S. — "Caspar ACV Research Project Report No. 4, Program I, The Multicell Skirt, A Summary" Associate Committee on Air Cushion Technology of the National Research Council of Canada, Tech Report 5/76

2. House, W.C. Eggington, W.J. Lysdale, C.A. — "Evolution of the Air Cushion" SAE Paper 710182, January 1971