Technical Comments

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Comment on "Effects of Fan, Ducting and Powerplant Characteristics on the Cushion Stability of Air Cushion Vehicles"

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Nomenclature

h = hovergap
$\dot{m}_c$ = mass flux of air from fan to cushion
$\dot{m}_a$ = mass flux of air from cushion to atmosphere
S_a = cushion support or footprint area
t = time
V_c = total cushion volume when hovering
V_d = cushion volume when not hovering

IN the May 1981 issue of this Journal, Matsuo and Matsuo describe an analysis of the effect of fan, ducting and powerplant characteristics on "the cushion stability of vertically oscillating air cushion vehicles"[1] (ACV). While it appears that their assessment of the literature cited by them is accurate, apart from an introductory text[2] and their own work, they have not considered anything which has appeared since 1965. A representative sample of the literature that has been published up to 1978 is given below.[3-13] As might be expected, considerable progress in understanding the self-excited heave oscillation phenomenon and related ACV dynamical problems has been made in this period.

For example, the authors developed their analysis by assuming that the vertical "oscillatory motion is slow enough for the quasistatical treatment to be valid and that the compressibility of the air cushion is to be neglected."[1] It has been known since 1967[3] that neither assumption is valid. Air cushions of both the peripheral jet and plenum chamber type can be statically stable but dynamically unstable. For the simplest case, a rigid wall plenum chamber, this instability occurs directly as a result of the compressibility of the air in the cushion.[10] In physical terms, this is because, in the equation that couples the heave dynamics to the fluid flow processes, namely, the cushion volume conservation law:

$$\frac{d}{dt}(\rho_c V_c) = \dot{m}_c - \dot{m}_a, \qquad V_c = S_a h + V_d \tag{1}$$

Usually $V_d \gg S_a h$, so that the variation of the mass of air stored in V_d by virtue of compression is comparable to that stored by variation of the hovergap. For the cushion pressures low enough for the flow processes to be incompressible, the cushion volume has therefore to be modelled as a lumped pneumatic capacitance.

The effect of ducting on ACV dynamics has been explored in some detail.[10,11,13,14] Sweet, Richardson, and Wormley[10] investigated this problem in the high speed guided ground vehicle context. They modelled the duct process by the equations of one-dimensional acoustics and presented some experimental results for frequency response; these agreed well with their analysis. They conclude that, for the application of interest to them, in which an air cushion pad is connected to the vehicle by a soft mechanical secondary suspension, ducting could have a major effect on the dynamics of the pad, but it would have little effect on the vehicle. More recently, Hinchey and Sullivan,[13] by using both linear stability analyses and nonlinear numerical simulations, concluded that even the relatively short ducting that might be used on amphibious ACV's could have a major effect on dynamics and stability. Their analysis, which was based on the well-known equations for hydraulic transients, showed that the inertance of the duct air accounted for most of these effects. The frictional losses modelled by Matsuo and Matsuo[1] were found to have a negligible effect on the dynamics.

Significant unsteady fan dynamic effects can also occur. They can arise from two sources: unsteady blade aerodynamics in the rotor-stator system, and inertia effects in the volute or annulus of the fan.[11,12,14] Neither of these are modelled by assuming quasisteady fan behavior, as was done by Matsuo and Matsuo.[1] For the self-excited oscillation problem, the frequencies involved are usually relatively low, so that the unsteady blade aerodynamics effects are negligible; but the second can be important for practical systems.[12] However, there are ACV dynamic problems—such as high speed flight over waves of small wavelength—where true unsteady blade aerodynamic effects occur.[11]

In work completed recently at this writer's laboratory, Hinchey[15] has obtained an accurate experimental confirmation of the very large duct effects on stability reported in Ref. 13. Also, it has been shown that the nonlinearities that are characteristic of the flexible-skirted plenum chamber cushions now widely used in modern vehicle designs will generally cause an ACV to limit cycle if it is dynamically unstable.[16] Finally, Graham[17] has shown that the materials that are used to model flexible skirts can themselves have a major effect on dynamic stability. This is, in part, caused by skirt deformation under the action of cushion pressures, which in turn can add large increments to the pneumatic capacitance of V_d. However, viscoelastic properties of skirt materials may also play a role.

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Reply by Author to P. A. Sullivan

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I APPRECIATE very much the attention that Dr. Sullivan has given to my paper.[1] The purpose of my paper is to propose a method which can serve as a practical procedural tool to estimate the stability at the initial stage of ACV design. Even though it is incomplete in setting up assumptions as Dr. Sullivan has criticized, I believe that it would serve at least for this purpose.

Dr. Sullivan has indicated three points which are not considered in my analysis; they are

1) Compressibility of air (air flowing through ducts and air in the cushion cavity).

2) Dynamic (unsteady) effects appearing in flow motions in fans, fan rotor-stator systems, ducts and the cushion.

3) Aero- and visco-elastic effects of skirts.

These would actually cover almost all the effects which are to be considered in ACV stability analysis, and I know, of course, about the basic studies which have dealt with some of these effects in the past 15 years. Substantially, I agree with Dr. Sullivan's opinion and his comment would be correct inasmuch as the works cited by him are correct.

As indicated by Dr. Sullivan, considerable progress has been made since 1965, but I consider, not all of the results are universally or directly applicable to the practical estimation and design of ACV stability, since, besides the complexities involved in analyses, there are various types of air cushion application, such as TLV (tracked levitated vehicles), marine ACV's and aircraft landing gears, and the types of the air feeding system, the magnitude of cushion pressure and the oscillation frequency differ among these applications. One example would be given here. Some of the analyses made since 1970 have aimed mainly at the application to TLV where the combination of a straight duct and a chamber would be a realistic model. In ACV's (particularly in marine ACV's), the air feeding system is composed of complex combinations of ducts and chambers. Even though I do appreciate, of course, that recent analyses have made some contributions in studying the effects 1-3 mentioned above and that they would give some estimations of these effects, I can not find a way actually to apply them to the construction of a practical procedural tool.

Under these situations, I have taken another way, where I have developed simple analyses[2,3] based on simple assumptions (quasistatical motion of incompressible fluids), compared the results with experiments or practice and empirically modify them if necessary. According to the results of my own studies[3,4] the consideration of quasistatic characteristics of all of the fan, ducting and powerplant has so much improved the results as to be applied to the practice.

I believe that, at least in the practice of marine ACV's, in the development work of which I was personally engaged for 8 years at Mitsubishi Heavy Industries Ltd., Japan, the method I proposed in Ref. 1 can serve as a procedural tool for the practical estimation and design of stability.

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