HYDRODYNAMIC NOTE AG-18

FLAP CONTROL OF INCIDENCE HINGE MOMENT
AND FOIL CAVITATION

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SUMMARY

The use of flaps to control the incidence hinge moment and cavitation characteristics for incidence lift control foils is examined in the light of the measured prototype lift and moment characteristics of Reference 3. The flap management considered here is a function of speed and is critical only at minimum flight speed, to avoid crossover, and at maximum speed, to avoid exceeding design hinge moment. The numerical summary is for the AG(EH) fwd. foils but is typical for foils of any size and of any speed less than 50 - 60 knots.

Trailing edge flaps would reduce the existing incidence lift control hinge moment about 40%. The existing hinge moment could be reduced about 60% by also changing the hinge position but that moment would be bidirectional and is considered to present an intolerable crossover problem. Hinging for positive hinge moment rather than negative, would double the moment. Abnormal flap chords do not aid moment or cavitation control, and flaps do not relieve the requirement to design the basic section for the design speed.

The flaps can be employed to increase the incipient cavitation foil loading by some 400 psf cr to increase the cavitation speed by up to about 10 knots. This cavitation control can be extended by incorporating the section geometry into the control procedure. Flap control of cavitation is not state of the art, being dependent upon the effective cavitation boundaries which are unknown for the flapped foil.
h-ailing edge flaps do not provide control over the flying foil.

The Interim Report conclusion that an appropriately selected fixed incidence angle would provide the flap lift control system with the optimum incipient cavitation bucket was a coincidental result of the numerical value assigned $\zeta$ in that report. A confident evaluation of this parameter will probably compromise the optimum bucket for the fixed incidence, flap lift control system.
INTRODUCTION

Incidence lift control provides three qualitative advantages over flap lift control:

1. Superior cavitation characteristics,
2. Lower (profile) drag,

None of these advantages can be evaluated quantitatively yet, even to establish whether the differences are significant or not, because no confidence level has yet been established for the performance of the flap lift control system.

The only disadvantage associated with incidence lift control is the high hinge moment relative to the flap lift control system but this is a real disadvantage which has already produced design and operational difficulties. Reference 1 demonstrates that unflapped incidence lift control hinge moments are generally proportional to craft displacement and that the PGH-1 and AG(EH) hinge moments are characteristic.

This note is intended to employ the results of Reference 2 to examine the feasibility for adjustable flap control of the hinge moments for an incidence lift control system including the case for the "flying" flap controlled foil. A closely related problem, employment of flaps for the control of the incipient cavitation bucket, is included for completeness.

The general equations developed in this note are illustrated by application to the AG(EH) foil geometry but are, of course, applicable to any foil configuration.
CONCLUSIONS

1. The maximum incidence lift hinge moment is increased by:
   A. Spreading the minimum and maximum foil loading,
   B. Increasing the normal acceleration margin requirement,
   C. Spreading the minimum and maximum flight speed,
   D. Reducing the nominal minimum submergence,
   E. Allowance for prediction precision for:
      a. aerodynamic center,
      b. residual moment,
      c. flap load distribution, $\zeta$

2. Flaps will reduce the maximum hinge moment by about 40% and will compensate for the prediction errors of 1 E, above.

3. Hinging for bi-directional moment reduces the hinge moment about 35% more but not to a tolerable level for crossover. Hinging for positive moment doubles the moment.

4. Moments for the various hinge and flap schedule options are compared numerically in Table VII.

5. Flaps can increase the incipient cavitation foil loading by 400 psi or increase the incipient cavitation speed by up to 10 knots (See Figure 17).

6. Intelligent flap scheduling will always improve the hinge moment and the incipient cavitation bucket but the optimum flap schedules are not the same for the two objectives.

7. Optimum hinge positions are summarized in Table V and the corresponding maximum moments are summarized in Table VI.
8. A more concise derivation of the cavitation equations of the Interim Report including accountability for buoyancy and extending the results to the case for the flapped incidence lift control foil, is presented in this note. Eq. (24) presents the incipient cavitation foil loading for flap lift control and Eq. (29) presents this foil loading for the flapped incidence lift control system. Eq. (29) includes the case for the unflapped foil.

9. The hinge moment equation of this note, Eq. (30), includes the unflapped hinge moments of Reference 1 as a special case.

10. All of the moment and cavitation results of this note are subject to inadequate confidence levels for the hydrodynamic characteristics of flaps; specifically for the parameter, $\zeta$, and for the flapped effective cavitation boundaries.

11. The trailing edge flap will not control the "flying" foil because the flap angles required are intolerable for cavitation.

12. The Interim Report conclusion that an appropriately selected fixed incidence angle would provide the flap lift control system with the optimum incipient cavitation bucket was a coincidental result of the numerical value assigned $\zeta$ in that report. A confident evaluation of this parameter will probably compromise the optimum bucket for the fixed incidence, flap lift control system.

13. Existing flap lift control prototypes are not, necessarily, models of future designs. If future prototypes are to be designed with confidence, the general theory for flapped hydrofoils must be experimentally validated.
RECOMMENDATIONS

1. An adequate map of the effective cavitation boundaries for some, any, flapped hydrofoil is urgently required. The AG(EH) foil would be an ideal model for this map because of the theoretical and experimental background already available for this configuration. The AG(EH) configuration is also ideally suited to Be Grumman whirling tank in span and aspect ratio and will provide this map more economically and more reliably than any existing facility. It is therefore recommended that Grumman's "Proposal for Extension To AG(EH) Lift Control Study For Cavitation Sealed Model Testing", October 1972, be undertaken without further delay. No general theory for flapped foil performance, incidence or flap lift control, can be formulated in the absence of this map. Any prototype built without this map is an experimental prototype.

2. A general theoretical and experimental attack upon the hydrodynamic characteristics of the flapped foil is required though no such program is formulated here.

3. Theoretical and experimental examination of the possibility for extending the conventional foil speed range by the use of flaps is recommended though no such program is formulated here.

4. Theoretical and experimental examination of the characteristics of a flying foil controlled by a boom mounted foil is recommended though no such program is formulated here.
5. **Recommendations** with regard to the "Plainview", specifically, as a result of the studies of this note are reserved for completion of studies of flap hinge moment and control **power**.
DISCUSSION

BASIC EQUATIONS

Alternative forms of the total lift equation for the foil with flap are:

\[
\frac{C_{LH}}{C_{Ld}} \frac{C_L}{C_{Ld}} = C_{Ld0} \frac{(W/S)_H}{(W/S)_d} + C_{Ld} \alpha + C_{Ld} l' + C_{Ld} \delta_\infty s + C_{Ld} \infty
\]

(1)

\[
= C_{Ld0} \alpha + \frac{C_{Ld}}{C_{Ld}} C_{Ld0} l' + \frac{C_{Ld}}{C_{Ld}} C_{Ld} \delta_\infty s + C_{Ld} \infty
\]

The corresponding foil loading equation is particularly useful to this note:

\[
\frac{C_{Ld0}}{C_{Ld}} \frac{(W/S)_H}{(W/S)_d} = (W/S)_{d0} + \frac{(W/S)}{C_{Ld}} l' + \frac{(W/S)}{C_{Ld}} \delta_\infty + \frac{(W/S)}{C_{Ld}} \infty
\]

(2)

\[
= (W/S)_{d0} + \frac{(W/S)}{C_{Ld}} \delta_\infty + \frac{(W/S)}{C_{Ld}} \infty
\]

where \( (W/S)_d \) accounts for orbital angle of attach or for craft pitch, \( \theta \).

The hinge moment analyses of this note assume, as in References 1 and 2, that \( C_{HC_L} = C_{H_{dL}} = C_{HC_L} \), so that the total hinge moment is given by:

(3) \[ H = C_{HC_L} C_d \alpha \gamma_{SMAC} + C_{HC} C_l l' \gamma_{SMAC} + C_{H_o} C_{Ld} \delta_\infty \gamma_{SMAC} + C_{H_o} \gamma_{SMAC} + H_B \]

\[
\frac{H}{SMAC} = C_{HC_L} \left( C_d \alpha + C_l l' \right) \gamma + C_{H_o} C_{Ld} \delta_\infty \gamma + C_{H_o} \gamma + \frac{H_B}{SMAC}
\]
It is convenient for the purpose of this note to consider the buoyant hinge moment in the form:

\[ H_B = \left( \frac{H}{c} - b \cdot c \right) \frac{M \cdot A \cdot C}{S} \times \left( \frac{W}{S} \right)_B \]

\[ \frac{H_B}{S \cdot M \cdot A \cdot C} = \left( \frac{H}{c} - a \cdot c + a \cdot c - b \cdot c \right) \left( \frac{W}{S} \right)_B \]

\[ = \left( C_{HcL} + a \cdot c - b \cdot c \right) \left( \frac{W}{S} \right)_B \]

In Reference 2 the \( C_{HcL} \) has been defined as:

\[ C_{HcL} = C_{HcL} - \frac{1}{4} \left( 1 + \frac{T_{\alpha}}{T_{\alpha 0}} \right) \]

\[ = C_{HcL} - \Delta \]

where the symbol \( \Delta \) is employed for brevity.

The zero lift hinge moment is not all defined for the flapped, incidence lift control foil because there are many combinations of pitch, incidence, and flap angle which will produce a zero lift, all with different zero lift hinge moments. For the particular case where the pitch and incidence lift aerodynamic center are the same however, \( C_{HcL} = C_{HcL_0} \), the residual hinge moment can be related to the zero-flap, zero lift hinge moment by:

\[ C_{H0} = C_{HcL=0} + C_{HcL} C_{L0} \]
where the prime is a reminder that the relationship must be evaluated for common pitch and incidence lift aerodynamic centers and for zero flap.

Substituting Eqs. (4) - (6) in Eq. (3):

\[
\frac{H}{\text{sl} \tau_c} = C_{H_{c_2}} \left( C_{a_d \alpha_1} + C_{c_i} \right) \tau + \left( C_{H_{c_1}} - \Delta \right) C_{L_s} S \frac{g}{s} \\
+ C_{H'_{c_1}} \tau + C_{H_{c_2}} C_{L_0} \tau + \left( C_{H_{c_1}} + a_c - b_c \right) \left( \frac{W}{S} \right)_B
\]

\[
= C_{H_{c_2}} \left[ \left( C_{a_d \alpha_1} + C_{c_i} i + C_{L_s} S + C_{L_0} \right) \tau + \left( \frac{W}{S} \right)_B \right] + \left( a_c - b_c \right) \left( \frac{W}{S} \right)_B - \Delta C_{L_s} S \tau + C_{H'_{c_1}} \tau
\]

\[
= C_{H_{c_2}} \left[ \left( \frac{W}{S} \right)_H + \left( \frac{W}{S} \right)_B \right] + \left( a_c - b_c \right) \left( \frac{W}{S} \right)_B - \Delta \left( \frac{W}{S} \right)_B + C_{H'_{c_1}} \tau
\]

For brevity, \( \beta \) is defined to be

\[
\beta = \left( a_c - b_c \right) \left( \frac{W}{S} \right)_B
\]

Only one term of Eq. (7) is depth sensitive and that term is more conveniently written:
Then Eq. (7) may be written

\[ C_{HcL} = 0 = \frac{C_{Ld}}{C_{Ld0}} C_{Hd0} C_{L} = 0 \]

which is the form employed for the moment analyses in following sections.

From References 2 - 4 the following coefficients are practical for the AG(EH) foils with 20% chord flaps at infinite depth:
\[ C_{\text{L},0} / C_{\text{L},0} = 0.838 \]
\[ \frac{\text{d} d}{\text{d}s} = 0.467 \]

\[ C_{\text{L},0} = 2.97 / 0.0519 / \text{deg}. \]
\[ C_{\text{L},\infty} = 0.838 \times 2.57 = 2.15 = 0.0435 / \text{deg}. \]
\[ C_{\text{L},\infty} = 0.467 \times 2.49 = 1.164 = 0.0203 / \text{deg}. \]
\[ C_{\text{L},0\infty} = 0.111 \]

\[ C_{\text{H},V} = C_{\text{H},0\infty} = C_{\text{H},0} = 0.07 \quad \text{(existing)} \]
\[ \Delta = \frac{1}{4} \left(1 + \frac{\text{F}_{\text{ail}}}{\text{F}_{\text{ail}}} \right) = 0.185 \]
\[ C_{\text{H},0} = C_{\text{H},V} - \Delta = 0.07 - 0.1752 = -0.1152 \quad \text{(existing)} \]
\[ C_{\text{H},0\infty} = -0.0608 \]
\[ C_{\text{H},0\infty} = C_{\text{H},0} - C_{\text{H},0}\infty = -0.0686 \quad \text{(prototype)} \]

\[ C_{\text{H},0\infty} = C_{\text{H},V} / C_{\text{L},0\infty} = 2.97 \times 0.07 = 0.0208 = 0.00363 / \text{deg}. \quad \text{(existing)} \]
\[ C_{\text{H},0\infty} = C_{\text{H},V} / C_{\text{L},0\infty} = 2.49 \times 0.07 = 0.1744 = 0.00304 / \text{deg}. \quad \text{(existing)} \]
\[ C_{\text{H},0\infty} = C_{\text{H},0\infty} / C_{\text{L},0\infty} = 1.164(-0.115) = -0.1342 = -0.002345 / \text{deg}. \quad \text{(existing)} \]
It is to be noted that the nominal minimum foil depth is quite arbitrary. Grumman prefers to employ that depth for which the nominal maximum foil loading will not ventilate the foil. That depth is an experimental characteristic which has not been established for the AG (EH) foil system and the MAC depth is assumed.
CAVITATION REVIEW

A proper appreciation for the potentialities of Eq. (10) requires a better intuitive appreciation for the effect of flaps on cavitation than is provided by Reference 4 and the subject is therefore reviewed here. This review will also provide an opportunity to incorporate the revised evaluation for the parameter $f$ of Reference 2 and to provide accountability for buoyant lift, which was not mentioned in Reference 4.

The following derivation for the cavitation foil loading is more concise than that of Reference 4 and therefore, perhaps, more satisfying intuitively.

The pressure coefficient, $S$, on the section perpendicular to the quarter-chord line is given by:

\[
S = \frac{V}{V} \pm \frac{\Delta V}{V} \pm \frac{\Delta \gamma}{V} \left[ (C_{l_H} - C_{l_b}) - C_{l_v} \right] \pm \frac{(\Delta \gamma)}{F} C_{l_b}^l
\]

- basic flap load distribution
- additional load distribution (angle of attack)
- camber distribution (distribution for $C_{l_i \ eff}$)
- distribution for thickness distribution

where primes indicate plane perpendicular to quarter-chord

The parameters $\psi$ and $\zeta$ are defined in Reference 4.

\[
\psi = \frac{V}{V} \pm \frac{\Delta V}{V} + \frac{\Delta V \alpha}{V} C_{l_i \ eff}
\]
(14) \[ S = C\ell_b / C\ell_f \]

Then Eq. (12) may be written:

(15) \[
\sqrt{S} = \frac{V}{V} \pm \frac{Lh}{V} \cdot C\ell_{\text{eff}} \pm (C\ell'_b - C\ell_b) \frac{Lh}{V} \pm (\frac{Lh}{V})_f \cdot C\ell_b \\
= \sqrt{S} \pm (C\ell'_b - C\ell_b) \frac{Lh}{V} \pm (\frac{Lh}{V})_f \cdot C\ell_b \\
= \sqrt{S} \pm (C\ell'_b - S \cdot C\ell'_{\text{inc}}) \frac{Lh}{V} \pm S (\frac{Lh}{V})_f \cdot C\ell_f
\]

The total hydrodynamic lift coefficient, \( C_{1H} \), includes the effective design lift coefficient (camber) plus pitch, incidence, and flap components:

(16) \[
\sqrt{S} = \sqrt{S} \pm \left[ (C\ell'_{\text{inc}}) + (C\ell'_{\text{flap}}) + (C\ell'_{\text{inc}}) \right] \frac{Lh}{V} \pm \sqrt{S} (\frac{Lh}{V})_f \cdot (C\ell'_{\text{flap}})
\]

Each of these components of the section lift coefficient is related to the corresponding foil average lift coefficient component by the appropriate spanwise lift distribution where it is to be noted that the spanwise distribution for camber lift is identical with that for incidence lift:
Multiplying this equation through by \( Q \) we obtain foil loading components which are independent of the flow orientation. Note that the product, \( q' \) \( C'_l \) }_{\text{eff}} \text{ is a theoretical } \left( \frac{W_{q'}}{S} \right) \text{ which is identified with the experimental value at this point. (for } \omega = \omega_{\text{mean}}) \)

(18)

\[
(\sqrt{5} - \nu)c' = \pm \left[ (\frac{c'_d}{c_d})_d (\frac{c'_d}{c_d})_d + (\frac{c'_c}{c_c})_c (\frac{c'_c}{c_c})_c + (\frac{c'_b}{c_b})_b (\frac{c'_b}{c_b})_b + (\frac{c'_a}{c_a})_a \right] \frac{\Delta_{\text{v}}}{\nu}
\]

\[
\pm (\sqrt{5} - \nu)c' = \left[ (\frac{c'_d}{c_d})_d (\frac{c'_d}{c_d})_d + (\frac{c'_c}{c_c})_c (\frac{c'_c}{c_c})_c + (\frac{c'_b}{c_b})_b (\frac{c'_b}{c_b})_b \right] \frac{\Delta_{\text{v}}}{\nu}
\]

\[
+ (1 - \delta) (\frac{c'_a}{c_a})_a (\frac{c'_a}{c_a})_a \frac{\Delta_{\text{v}}}{\nu} + (1 - \delta) (\frac{c'_a}{c_a})_a (\frac{c'_a}{c_a})_a \frac{\Delta_{\text{v}}}{\nu}
\]

\[
= \left[ (\frac{c'_d}{c_d})_d (\frac{c'_d}{c_d})_d + (\frac{c'_c}{c_c})_c (\frac{c'_c}{c_c})_c + (\frac{c'_b}{c_b})_b (\frac{c'_b}{c_b})_b \right] \frac{\Delta_{\text{v}}}{\nu}
\]

\[
+ S \left[ \left( \frac{c'_d}{c_d} \right)_d - \frac{\Delta_{\text{v}}}{\nu} \right] (\frac{c'_d}{c_d})_d (\frac{c'_d}{c_d})_d + \frac{\Delta_{\text{v}}}{\nu} (\frac{c'_d}{c_d})_d (\frac{c'_d}{c_d})_d
\]

The parameter, \( \omega \), was defined in Reference 4 for convenience:
\[ \omega = s \left[ \frac{(\frac{w}{s})_{d}}{V} - \frac{\frac{w}{s}}{V} \right] \]

and Eq. (18) may be written

\[ \pm (\sqrt{5} - \gamma) q' = \left[ \left( \frac{w}{s} \right)_{d} \left( \frac{w}{s} \right)_{d} + \left( \frac{w}{s} \right)_{i} \left( \frac{w}{s} \right)_{i} + \left( \frac{w}{s} \right)_{o} \left( \frac{w}{s} \right)_{o} \right] \frac{\Delta \frac{w}{s}}{V} \]

\[ - \omega \left( \frac{w}{s} \right)_{s} \left( \frac{w}{s} \right)_{s} + \frac{\Delta \frac{w}{s}}{V} \left( \frac{w}{s} \right)_{s} \left( \frac{w}{s} \right)_{s} \]

\[ = \left[ \left( \frac{w}{s} \right)_{d} \left( \frac{w}{s} \right)_{d} + \left( \frac{w}{s} \right)_{i} \left( \frac{w}{s} \right)_{i} + \left( \frac{w}{s} \right)_{o} \left( \frac{w}{s} \right)_{o} \right] \frac{\Delta \frac{w}{s}}{V} \]

\[ + \left( \frac{\Delta \frac{w}{s}}{V} - \omega \right) \left( \frac{w}{s} \right)_{s} \left( \frac{w}{s} \right)_{s} \]

where:

\[ s = 1 + \frac{p_{o} - p_{v} + \rho gh}{\rho V} = 1 + \omega' \]

\[ \frac{w}{s} = \left( \frac{w}{s} \right)_{d} + \left( \frac{w}{s} \right)_{i} \left( \frac{w}{s} \right)_{i} + \left( \frac{w}{s} \right)_{o} + \left( \frac{w}{s} \right)_{o} + \left( \frac{w}{s} \right)_{B} \]

\[ = \left( \frac{w}{s} \right)_{H_{eff}} + \left( \frac{w}{s} \right)_{d} \left( \frac{w}{s} \right)_{o} \left( \frac{w}{s} \right) + \left( \frac{w}{s} \right)_{B} \]

\[ = \left( \frac{w}{s} \right)_{H} + \left( \frac{w}{s} \right)_{B} \]

W/S is the incipient cavitation foil loading for any given \( \sqrt{s} \) and \( q' \)
(or \( q \)) and Eq. (20) is the most general form of the relationship.

For a flap lift control system Eq (20) is more conveniently handled by:
Substituting in Eq. (20):

\[ \pm (\sqrt{5} - \nu) g' = \left( \frac{c_s}{c_e} \right)_d \left( \frac{w}{s} \right)_a + \left( \frac{c_s}{c_e} \right)_b \left( \frac{w}{s} \right) \text{ref} \]
\[ + \left[ \frac{w}{s} - \left( \frac{w}{s} \right)_\text{ref} - \left( \frac{w}{s} \right)_d - \left( \frac{w}{s} \right)_B \right] \left( \frac{c_s}{c_e} \right) \left( \frac{w}{s} \right) - \omega \]
\[ = \left( \frac{c_s}{c_e} \right)_d \left( \frac{w}{s} \right) - \omega \frac{w}{s} + \left[ \left( \frac{c_s}{c_e} \right)_b \left( \frac{w}{s} \right) - \left( \frac{c_s}{c_e} \right)_a \left( \frac{w}{s} \right)_\text{ref} \right] \left( \frac{c_s}{c_e} \right) \left( \frac{w}{s} \right) - \omega \left( \frac{w}{s} \right)_B \]
\[ + \left[ \left( \frac{c_s}{c_e} \right)_d \left( \frac{w}{s} \right) - \left( \frac{c_s}{c_e} \right)_b \left( \frac{w}{s} \right)_\text{ref} \right] \left( \frac{c_s}{c_e} \right) \left( \frac{w}{s} \right) - \omega \left( \frac{w}{s} \right)_B \]
\[ \pm (\sqrt{5} - \nu) g' = \left( \frac{c_s}{c_e} \right)_d \left( \frac{w}{s} \right) - \omega \frac{w}{s} + \left[ \left( \frac{c_s}{c_e} \right)_b \left( \frac{w}{s} \right) - \left( \frac{c_s}{c_e} \right)_a \left( \frac{w}{s} \right)_\text{ref} \right] \left( \frac{c_s}{c_e} \right) \left( \frac{w}{s} \right) - \omega \left( \frac{w}{s} \right)_B \]
\[ + \left[ \left( \frac{c_s}{c_e} \right)_d \left( \frac{w}{s} \right) - \left( \frac{c_s}{c_e} \right)_b \left( \frac{w}{s} \right)_\text{ref} \right] \left( \frac{c_s}{c_e} \right) \left( \frac{w}{s} \right) - \omega \left( \frac{w}{s} \right)_B \]

The parameter, \( \xi \), is defined for convenience in Reference 4:

\[ \xi_d = \frac{\left( c_s/c_e \right)_d}{\left( c_s/c_e \right)} - 1 \]
\[ \xi_a = \frac{\left( c_s/c_e \right)_a}{\left( c_s/c_e \right)} - 1 \]

and Eq. (22) may be written:
Thich  is identical with Eq. (6.2.19) of Reference 4 except for the obvious refinement that the total W/S is now identified as the hydrodynamic foil loading.

For the case where the full exposed span is flapped Eq. (24) reduces to

\[
\frac{(\sqrt{5} - 1) \rho'}{c_1 \alpha} \left[ \frac{W}{3} - \frac{W}{3} b \right] + \left( \frac{\Delta V}{V} + \alpha \right) \left( \frac{W}{3} \right) \sigma \alpha
\]

\[
(\frac{\Delta V}{V} - \alpha) \left( \frac{W}{3} \right) = \frac{(\sqrt{5} - 1) \rho'}{c_1 \alpha} - \left( \omega + \frac{\Delta V}{V} \right) \left( \frac{W}{3} \right) \sigma \alpha
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\[
(\frac{\Delta V}{V} - \alpha) \left( \frac{W}{3} \right) = \frac{(\sqrt{5} - 1) \rho'}{c_1 \alpha} - \left( \omega + \frac{\Delta V}{V} \right) \left( \frac{W}{3} \right) \sigma \alpha
\]

which is Eq. (6.2.21) of Reference 4.

For the incidence lift control case for a flapped foil,

\[
\text{Let: } (\frac{W}{3})_i = \frac{W}{3} - (\frac{W}{3}) b - (\frac{W}{3}) c - (\frac{W}{3}) - (\frac{W}{3}) \alpha
\]

and substitute in Eq. (23):
\[ (27) \]
\[
\pm (\sqrt{5} - 2) \psi' = [\frac{\partial \psi}{\partial \nu} (\frac{\psi}{\nu})_0 + (\psi)^{\psi}_2 (\frac{\psi}{\nu})_0 + \left( \frac{\nu}{\nu} - (\frac{\psi}{\psi})_3 (\frac{\psi}{\psi})_0 - (\frac{\psi}{\psi})_4 (\frac{\psi}{\psi})_3 \right] \frac{\psi}{\psi}
\]
\[
+ \left( \frac{\nu}{\nu} - \omega \right) \left( \frac{\psi}{\psi} \right)_5 (\frac{\psi}{\psi})_3
\]
\[
= \left\{ (\psi)^{\psi}_4 (\frac{\psi}{\psi})_5 - (\psi)^{\psi}_2 (\frac{\psi}{\psi})_3 + \left[ (\psi)^{\psi}_6 - (\psi)^{\psi}_4 \right] (\frac{\psi}{\psi})_3 \right\} \frac{\psi}{\psi}
\]
\[
+ \left( \frac{\nu}{\nu} - \omega \right) \left( \frac{\psi}{\psi} \right)_5 (\frac{\psi}{\psi})_3
\]
\[
= \frac{\psi}{\psi} \cdot \frac{\partial \psi}{\partial \nu} \left( \frac{\psi}{\psi} \right)_5 + \left[ (\psi)^{\psi}_6 \left( \frac{\psi}{\psi} - \omega \right) - (\psi)^{\psi}_2 \frac{\psi}{\psi} \right] (\frac{\psi}{\psi})_5
\]
\[
+ \left[ (\psi)^{\psi}_4 - (\psi)^{\psi}_6 \right] \frac{\psi}{\psi} (\frac{\psi}{\psi})_3
\]

For the special case where the full exposed span is flapped, a very convenient reduction results by dividing through by \((c_1/c_2)_5\):

\[ (28) \]
\[
\pm \sqrt{\frac{\psi}{\psi}} = \frac{(c_1/c_2)}{(c_1/c_2)_5} \cdot \frac{\partial \psi}{\partial \nu} \left( \frac{\psi}{\psi} \right)_3 + \left[ \frac{\partial \psi}{\partial \nu} - \omega \left( \frac{\psi}{\psi} \right)_5 \right] (\frac{\psi}{\psi})_3
\]
\[
+ \left[ \frac{(c_1/c_2)_6 - (c_1/c_2)_5} {c_1/c_2}_5 \right] \frac{\partial \psi}{\partial \nu} \left( \frac{\psi}{\psi} \right)_5
\]
\[
= \frac{\partial \psi}{\partial \nu} \left( \frac{\psi}{\psi} \right)_5 - \omega \left( \frac{\psi}{\psi} \right)_5 + \omega \left( \frac{\psi}{\psi} \right)_5
\]
\[
\frac{\partial \psi}{\partial \nu} \left( \frac{\psi}{\psi} \right)_5 = \pm \sqrt{\frac{\psi}{\psi}} + \omega \left( \frac{\psi}{\psi} \right)_5 - \omega \left( \frac{\psi}{\psi} \right)_5
\]

[For \((c_1/c_2)_5 = (c_1/c_2)_6\) .]
For the more general case, however, it is more convenient to divide Eq. (27) through by \((c_1/c_L)_i\):

\[
\pm \frac{\sqrt{5} - k}{(c_1/c_L)_i} \xi' = \frac{\Delta \eta}{V} (\frac{w}{S})_H - \left[\frac{(c_1/c_L)_i}{(c_1/c_L)_o} (\frac{\Delta \eta}{V} - \omega) - \frac{\Delta \eta}{V}\right] (\frac{w}{S})_o \left[\frac{(c_1/c_L)_o}{(c_1/c_L)_i} - 1\right] \frac{\Delta \eta}{V} (\frac{w}{S})_o
\]

\[
\frac{\Delta^2 \eta}{V} (\frac{w}{S})_H = \pm \frac{\sqrt{5} - k}{(c_1/c_L)_i} - \left[\frac{(c_1/c_L)_i}{(c_1/c_L)_i} (\frac{\Delta \eta}{V} - \omega) - \frac{\Delta \eta}{V}\right] (\frac{w}{S})_o \left[1 - \frac{(c_1/c_L)_i}{(c_1/c_L)_o}\right] \frac{\Delta \eta}{V} (\frac{w}{S})_o
\]

which, of course, reduces immediately to Eq. (28) for

\[
(c_1/c_L)_o = (c_1/c_L)_i .
\]

Note that for the unflapped foil Eq. (29) reduce's to

\[
\frac{\Delta \eta}{V} (\frac{w}{S})_H = \pm \frac{\sqrt{5} - k}{(c_1/c_L)_i} + \left[1 - \frac{(c_1/c_L)_i}{(c_1/c_L)_o}\right] \frac{\Delta \eta}{V} (\frac{w}{S})_o
\]

(for incidence lift control with unflapped foil)

and if the foil is rigidly attached to the pod, \((c_1/c_L)_i = (c_1/c_L)_o\), there is a further reduction to:
\[
\frac{L_{\infty}}{V} (\frac{c}{\delta}) = \pm \left( \frac{\sqrt{5} - 2}{c_0 / c_L} \right)^2
\]

(for pitch lift control)

which is Eq. (6.1.4) of Reference 4.

Some inconsistencies have entered the AG(EH) study by way of interpolating the section characteristics and Figures 1 and 2 present graphical interpolations from the velocity distributions of Reference 6 to avoid this problem in the future.
For any given lift coefficient, whatever its components, the cavitation speed is proportional to the depth function:
Thus a cavitation bucket derived for any particular depth can be transformed to another depth by use of the functions:

\[ \frac{V_c}{V_{c_0}} = \sqrt{1 + \frac{\rho g h}{P_v - P_v'}} \]

\[ \frac{W/s}{(W/s)_0} = \left( \frac{V_c}{V_{c_0}} \right)^2 = 1 + \frac{\rho g h}{P_v - P_v'} \]

The function \( V_c/V_{c_0} \) is presented on Figure 3 for convenience in transforming the cavitation buckets of this note to other depths. Figure 3 was not employed in the derivation of the cavitation buckets of this note which were all derived directly from the equations of this section.

Figure 3 is valid only for the theoretical incipient cavitation bucket of course; there is no theoretical accountability at present for the cavitation inhibiting effect of the free surface.
UPDATING THE INTERIM REPORT

CAVITATION BUCKET

The AG(EH) fwd. foil incidence lift cavitation buckets of Reference 4 are inappropriate to this study for five reasons:

1. **Foil** buoyancy was not accounted for,
2. The **model** camber was presented rather than the prototype camber (for evaluation of the towing tank test results),
3. The depth was **model** depth (8.5 ft) rather than the 1 MAC depth (9.33 ft) **preferred** for this study,
4. Zero **pitch** was **assumed to** simplify the calculations while a more **realistic** pitch (1°) is preferred for this study,
5. The cavitation parameter, $\xi$, was reevaluated in Reference 2.

The first four modifications to the cavitation buckets of Reference 4 are discussed in this section and the effect of reevaluating $\xi$ is considered in a later section. The necessary section and cavitation characteristics are presented in Tables I and II.

Typical buoyant and depth effects are shown on Figure 5. The 8.5 ft. depth, zero buoyancy bucket of Figure 5 is almost identical with the incidence lift buckets of Reference 4 though that of Figure 5 was derived from Eq. (28). The top of the bucket of Figure 5 is almost a knot higher than that of Reference 4 for some reason not explored here though it was noted that the section bucket of Figure 6.2 of Reference 4 is slightly in error for the mid-chord stations.
Buoyancy is a scale effect, as discussed elsewhere in these notes, having a negligible value in model scale. The buoyancy effect of Figure 5, then, actually exists in the comparison of model and prototype data. Note that buoyancy shifts the bucket on the foil loading scale, by the value of the buoyant foil loading, while increasing depths expand the bucket at all three boundaries. Again it is to be noted that this depth effect is theoretical. Near the surface there is a significant and unpredictable cavitation inhibiting effect, most familiar on yawed struts.

The effects of pitch and camber are illustrated on Figure 6. The effect of pitch is slight because it represents a redistribution of the total lift between pitch and incidence lift. Increasing pitch expands all three boundaries because the spanwise lift distribution for pitch lift is more favorable than that for incidence lift.

Increasing camber lowers the top of the bucket and rotates the bucket about the axis to the right. The AG(EH) bucket top is much higher than necessary and substantially more camber could be added or, alternatively, a new section of inferior cavitation characteristics but more favorable $c_{mac}$ could be employed.

The prototype bucket of Figure 6 is employed as the basic, or reference, cavitation bucket throughout the rest of this note.
FLAP CONTROL OF CAVITATION

The principle employed here was introduced in Reference 4. In essence, the simultaneous solution of Eq. (28) evaluated for the leading edge and the flap hinge station on the upper surface is the flap foil loading, $C_{L,fl}$, which provides simultaneous incipient cavitation at those two stations and the corresponding total foil loading. This flap angle redistributes the unflapped incidence lift chordwise load distribution in an approximation for the ideal distribution for cavitation. An identical solution is provided by Eq. (25), which was the equation employed in Reference 4 except that the solutions are total foil loading and reference foil loading where reference foil loading and flap foil loading are related by the foil loading relationships in Eq. (20).

For the purpose of deriving this optimum cavitation bucket it is convenient to rearrange Eq. (28) in the form.

\[
\frac{\Delta \lambda}{V} \left( \frac{W}{S} \right)_H = \pm \frac{(\sqrt{5} - \gamma)}{(C_1/C_2)_S} \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right) + \alpha \left( \frac{W}{S} \right)_S - \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right) \alpha
\]

\[
\frac{\Delta \lambda}{V} \left( \frac{W}{S} \right)_H - \alpha \left( \frac{W}{S} \right)_S = \mp \frac{(\sqrt{5} - \gamma)}{(C_1/C_2)_S} \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right) - \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right) \alpha
\]

\[
\left( \frac{W}{S} \right)_H - \frac{\alpha}{\Delta \lambda/V} \left( \frac{W}{S} \right)_S = \pm \frac{(\sqrt{5} - \gamma)}{\alpha} \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right)_S - C_{Ld} \alpha \beta \gamma
\]

\[
\left( \frac{W}{S} \right)_H - \frac{\alpha}{\Delta \lambda/V} \left( \frac{W}{S} \right)_S = \pm \frac{(\sqrt{5} - \gamma)}{(\alpha)(\gamma)} \frac{\Delta \lambda}{V} \left( \frac{W}{S} \right)_S - \frac{C_{Ld} \alpha \beta \gamma}{\gamma} \left( \frac{W}{S} \right)_S
\]

\[
= \pm \frac{(\sqrt{5} - \gamma)}{\alpha} \left( \frac{W}{S} \right)_S - \frac{C_{Ld} \alpha \beta \gamma}{\gamma} \left( \frac{W}{S} \right)_S
\]
This is still in its most general form, appropriate for any station on any foil. Restricted to the upper surface of the AG(EH) foil, Eq. (34) becomes:

\[
(35) \quad \left( \frac{w}{2} \right)_\mu - \delta \left[ 1 - \frac{(\varphi'_{L})(\varphi'_{U})}{(\varphi'_{L})(\varphi'_{U})} \right] \left( \frac{\varphi'}{\delta} \right)_\mu = \left[ \frac{\sqrt{5} - \sqrt{2}}{1.31 \frac{a}{2}} \right] \left( \frac{\varphi'}{\delta} \right)_\mu - \frac{c_d d a}{\varphi' \varphi'_{U} S_0} \delta \mu
\]

\[
= \left[ \frac{\sqrt{5} - \sqrt{2}}{1.31 \frac{a}{2}} \right] \left( \frac{\varphi'}{\delta} \right)_\mu - \frac{0.048 (-0.105)}{1.68} \delta \mu \quad [\theta = 0]
\]

\[
= \left[ \frac{\sqrt{5} - \sqrt{2}}{1.31 \frac{a}{2}} + 0.00784 \right] \delta \mu
\]

The incipient cavitation foil loadings, flap schedules, and incidence angles provided by Eq. (35) for several section and operating parameters are shown on Figures 7 - 9. These figures relate the reference cavitation buckets of the Interim Report to the updated reference buckets of this note. The first curve of Figure 7 is the reference curve of the Interim Report and is for the model section. The difference between curves #1 and #2 is the advantage afforded by the increase in camber of the prototype. The difference between curves #2 and #3 presents some advantage in depth and pitch angle but mostly due to accountability for buoyancy. The flap load distribution parameter, \( \zeta \), has no effect on the boundary of Figure 7.
Figure 8 presents the flap schedules which produce the boundaries of Figure 7 and here the parameter $\zeta$ does make a difference. Throughout this note the revised definition of Reference 2 for $\zeta$ was employed to evaluate this parameter.

Figure 9 presents the incidence angles associated with the boundaries of Figure 7. These angles have no particular significance to the incidence control foil but the $\zeta$ comparison of Figure 9 is very significant to one conclusion of the Interim Report and is discussed in some detail in the next section.

The use of flaps as a cavitation control device suggests the use of a symmetric section with a 50% chord flap to approximate an $a = 1.0$ camber distribution of adjustable design lift coefficient. Figure 10 presents an evaluation of this possibility. The results indicate that the basic section must be designed for the design speed conditions, though flaps can be employed to unload the leading edge at low speed and improve the boundary there.

Figure 10 indicates that larger flaps improve the cavitation bucket slightly but the structural disadvantage is considered too great for further consideration. The flap schedules and incidence angles for the boundaries of Figure 10 are presented on Figures 11 and 12 for information but only the prototype section of 20% chord flap is considered further in this note.
Figure 10 presents a relatively confident incipient cavitation advantage for the flaps but no conclusions can be drawn about the effects of flaps on the effective cavitation boundaries in the absence of an adequate experimental cavitation map for some, any, flapped foil.
CORRECTING AN INTERIM REPORT CONCLUSION

The boundary incidence angles of Figure 9 are the optimum (cavitation) incidence angles for the flap lift control foil. The Interim Report concludes, on the basis of curve #1 of Figure 9, that the incidence for the flap lift control foil could be permanently fixed at an angle which would produce the optimum cavitation bucket at any speed. Figure 9 indicates that the near-zero slope of curve 1 is a coincidental result of the evaluation adopted for $\zeta$ in the Interim Report. That indication has been confirmed by a calculation, not shown, for curve 1 with a $\zeta$ of .65 which has a substantial negative slope for the curve throughout.

Neither $\zeta$ value of Figure 9 is adequately supported and no confident consideration can be given to the incidence angle for the flap lift control foil until such experimental support is provided.
REFERENCE FLAP SCHEDULES

The three flap schedules of Figure 13 are investigated in detail in this note. The first schedule is the degenerate case of the unflapped foil, \((W/S)\gamma = 0\). The second case is the "optimum cavitation" schedule of Figure 11 for the AG(EH) prototype with a 20\% chord flap and with the revised \((.466)\) value for \(C\). The third case will be developed more fully in a later section but has a slope of:

\[
\frac{d\left(\frac{W}{S}\right)\gamma}{df} = C_{\text{Hoc}} \frac{1}{\Delta} = -0.0686/11.852 = -0.37
\]

This slope is passed through the aerodynamic 30\(^\circ\) flap foil loading at a minimum flight speed of 30 knots:

\[
\left(\frac{W}{S}\right)\gamma_{30\text{K}} = G_{\text{Slo}} \times 30^\circ \times 730\text{K}
\]

\[
= 0.0203 \times 30 \times 2550
\]

\[
= 1552
\]

The flap schedule of Eqs. \((36)\) and \((37)\) is referred to as the "optimum moment" schedule for reasons to be developed later.
REFERENCE CAVITATION BUCKETS

The cavitation buckets for the three flap schedules of Figure 13 are presented on Figures 14 - 17. Figures 14 - 16 present the construction of the cavitation buckets because it is instructive to view the relationship between the incipient cavitation speeds for all of the chord stations; i.e., the variation of chordwise pressure distribution with speed.

Only the stations bracketing the cavitation bucket (see Tables III & IV) have been considered in this note to conserve time. Where movement of the chord station for initial cavitation is indicated, as on the upper surface, leading edge boundary of Figure 14, it is obvious that intermediate stations would provide a more detailed boundary though the difference would be insignificant.

The spacing of the individual station boundaries of Figure 14 is a qualitative indication of the chordwise spread of cavitation as the incipient boundary is more deeply penetrated; the spanwise load distribution of Figure 6.1 of Reference 4 provides the same qualitative indication of the spanwise spread of cavitation.

Close station boundary spacing, for unit chordwise stations, indicates rapid cavity growth and a relatively "hard" boundary. The upper right corner of the bucket, then, is the "hardest" region of the bucket because the boundaries for every station pivot about a point near this corner; this is perhaps seen more clearly on Figure 6.2 of Reference 4. The effective cavitation boundaries (peak lift, cavitation drag, etc.) all spring from the incipient bucket at this corner. The upper surface leading edge boundary is so "soft" that it carries no significance.
The upper surface, mid-chord and lower surface, leading edge boundaries have never been mapped. The upper surface is expected to be a hard boundary since at least 20% of the chord is on the verge of cavitation here. The lower surface boundary is expected to be soft except that propeller experience indicates that the erosion boundary may coincide with the incipient boundary for the lower (pressure) surface.

These intuitive and poorly understood characteristics of the cavitation bucket must be borne in mind in evaluating the bucket. On Figure 15, for example, it is evident that the flap has shifted the bucket to higher foil loadings without affecting its general characteristics, Figure 16 presents a qualitatively different and very interesting flap effect. Here the bucket has been straightened up and 10 knots added to the top of the bucket. The "corner" of the bucket has been softened very substantially, The hinge line boundary is not significant because foils typically operate cavitated at low speed, because it is a very local condition which might not develop in practice, and because &light adjustment in the flap schedule would eliminate this boundary.

Remembering that Figure 16 results from the addition of a flap to an existing foil, with no consideration for cavitation, a very real potential for a high speed (~ 80 knot), cavitation free, conventional section foil is suggested here. Pursuit of this possibility, however, lies outside the scope of the AG(EH) lift study.
The three reference buckets are compared on Figure 17. The adequacy of the optimum moment bucket depends entirely upon its effective boundary and upon the normal acceleration requirement. The maximum foil loading indicated provides a $1/4$ margin over the $1435 \text{ psi}$ design foil loading and is probably extreme. Note that even with the hinge line boundary, the optimum moment bucket provides a lower cavitation-free speed at $1435 \text{ psi}$ than does the unflapped bucket.

Note that the optimum moment bucket intersects the optimum cavitation bucket at the speed for which they have a common flap angle on Figure 13. Similarly the optimum moment bucket intersects the unflapped bucket at the speed at which the flap schedule passes through zero on Figure 13. There is no comparable intersection between the optimum cavitation and unflapped buckets because the zero flap angle for optimum cavitation occurs at a speed above both buckets.
CLASSES OF MOMENT CONTROL (At: Intuitive Review)

**Symmetric Section**

The symmetric section has no \( \mu \) hence always presents a zero hinge moment when hinged at the aerodynamic center. Such a section does not present a useful incipient cavitation bucket at high speed, though its effective cavitation bucket has never been established, and has never been employed for hydrofoils. The symmetric section should be considered for low speed ad/or lightly loaded application however; e.g., this would appear to be the logical section for SMATH trim control. The hinge might be set off of the a.c. by a nominal amount to insure undirectional hinge moments.

**Cambered Section**

The cambered section is discussed in some detail in Reference 1. It presents hinge moments defined by

\[
C_H = C_{Hc} L + C_{Mac}
\]
where the $C_{MaC}$ is always negative for hydrofoils. Dimensionally the hinge moment is:

$$\frac{H}{SMAC} = C_H q = C_{HcL} \frac{W}{S} + C_{MaC} q$$

Because the moment is a function of $q$, no single hinge location ($C_{HcL}$) will produce a zero hinge moment over the speed range. This type foil must be hinged to produce a vanishing hinge moment at one flight speed extreme, accepting whatever results at the other flight speed extreme. The extreme moment is always less if the foil is hinged to produce a zero moment at minimum flight speed, which is why hydrofoil hinge moments are always negative.

Flapped (Incidence Lift Control) Section

In terms of the concept of lift-at-a.c./moment-about-a.c., Eq. (10) may be presented as:

$$C_{MaC} = \beta - \Delta (C_{\alpha})_{a.c.} + C_{HcL}$$
The alternative center-of-pressure concept is awkward for analysis and is not employed in the analysis of this note. It does have intuitive value however in identifying the significance of the coefficients of the moment equation. Presented in terms of centers of pressure, Eq. (10) may be presented as:

The chordwise pressure distributions present an even more fundamental view of the hinge moment equation and one which is particularly useful to an intuitive appreciation for this note. The buoyant lift and moment are omitted from this intuitive review for clarity.
The camber lift distribution is a function of the camber and for hydrofoils the \( a = 1.0 \) camber line is employed for cavitation reasons. Theoretically, then, the chordwise distribution of the camber lift with which we are concerned has the shape:

![Diagram of camber lift distribution](image)

\[ C_{L0} = C_{L} \, \text{(theoretically)} \]

\[ C_{m.a.c.} = -\frac{1}{4} C_{L} \]

The chordwise lift distribution due to pitch or incidence is the classic "additional" lift distribution, which is a function of section thickness distribution though the C.P. is about at the quarter-chord for any section:

![Diagram of chordwise lift distribution](image)

\[ a.c. = c/4 \]

\[ C_{m.a.c.} = 0 \]
The chordwise flap load distribution, in Allen's view, has two components, one identical with the "additional" lift distribution and one which is a function of flap chord:

![Diagram of chordwise flap load distribution](image1)

The optimum flap schedule for cavitation of Reference 4 makes the leading edge and hinge line pressure identical throughout the flight speed range thereby achieving almost a flat chordwise lift distribution throughout that range:

![Diagram of optimum flap schedule](image2)
As a consequence, the center of pressure remains at about half-chord throughout the flight speed range. This means that the cavitation control and mean hinge moment control objectives for the flap schedule are virtually identical since the foil could be hinged at the fixed c.p. position to provide a zero mean hinge moment across the speed range. The difficulty is that this is only the mean hinge moment, the lift for acceleration margin must still be supplied in the form of additional load distribution having its c.p. at the 1/4 chord point - 1/4 chord away from the zero mean moment hinge:

Therefore the zero mean moment foil still presents a maximum hinge moment of

\[
\frac{H_{\text{max}}}{S \text{MAC}} = \frac{1}{4} \times \left( \pm \Delta n \frac{W}{S} \right)
\]

For example the AG(EH) fwd foil, hinged and operated for a zero mean moment with \( \pm 1/4 \) g acceleration margins, would present a maximum moment of:
\[
\frac{H_{\text{max}}}{S\text{MAC}} = \pm \frac{1}{4} \times \frac{1}{4} \times 14.35 = 0.7 \text{ psf}
\]

\[
H_{\text{max}} \times 10^{-6} = \pm 0.0897 \times 2.1 = 0.1885 \text{ fl. lbs.} = 2.26 \text{ c. in. lbs.}
\]

compared with the existing 10 X PO\textsuperscript{6} in. lbs. The feasibility for the zero mean moment system, however, depends upon the feasibility for designing a control system to handle this moment with no significant angular discontinuity at crossover.

For the AG(EH) example the extreme c.p.'s are:

For the AG(EH) example the extreme c.p.'s are:

To make the moments undirectional there are the options for hinging at .583C where the maximum moment is:

\[
\frac{H_{\text{max}}}{S\text{MAC}} = +1.25 \frac{W}{S} (0.583 - 0.45) = 0.1663 \frac{W}{S} = 232 \text{ psf for } \frac{W}{S} = 14.35
\]

or at .45C where

\[
\frac{H_{\text{max}}}{S\text{MAC}} = -0.75 \frac{W}{S} (0.583 - 0.45) = -0.1 \frac{W}{S} = -143.5 \text{ psf for } \frac{W}{S} = 14.35
\]

and, in general, the maximum hinge moment will be reduced by the factor \((1-\Delta n)/(1+\Delta n)\) if the foil is hinged to produce negative undirectional moments rather than positive.
What has been reviewed **intuitively** here with respect to flap control of incidence hinge moment will be validated rationally in a later section but two **limitation** upon that analysis are noted here:

(1) **It is evident** that the thickness distribution, camber distribution and flap chord ratio could all be tailored for still further optimization of the cavitation and/or moment characteristics. Such efforts would overextend the existing accuracy state-of-the-art for flap cavitation and moment characteristics however and this analysis assumes the existing foil configuration with the anticipated 20% chord flaps.

(2) The optimum cavitation flap schedule is defined on the basis of the incipient cavitation bucket while it is the effective cavitation bucket, still totally unknown for flapped hydrofoils, which is significant. The **same** limitation, incidently, applies to the universal use of **16-series** sections and the a = 1.0 mean line for incidence lift control hydrofoils though no demonstrations are available that these sections are effectively or newer superior-to: older sections.

**THE REFLEXED SECTION**

Eq. (10) is repeated here for convenience:

$$\frac{H}{SMAC} = [C_{HL} \frac{W}{S} + B] - \left[ \Delta(C_L)_S - C_{HL}^{\prime} \right]$$
One way to produce a zero hinge moment throughout the speed range is to make both bracketed terms vanish; i.e.,

1. Set $\Delta (e)^{l}_o = C_{H_2} = 0$

2. Offset the hinge off of the a.c. only far enough to cancel the buoyant moment.

A trivial solution to the two requirements is provided by the unflapped, symmetric section but this solution is known to be inadequate for cavitation for a lifting foil. Thus the solution, if it exists, presents a cambered section with the flap deflected in opposition to the camber and by a fixed amount; i.e., the section is essentially a reflexed, unflapped section.

The general subject of reflexed sections lies far beyond the scope of this note but an evaluation of flap supplied reflex for one particular case will demonstrate a negligible probability of feasibility for reflexed sections generally for lifting foils.

For the AG(EH) fwd foils with 20% chord flaps, the requirement for a vanishing $q$ term in Eq. (10) implies:

$$ (e)^{l}_o = \frac{C_{H_2} = 0}{\Delta} $$

$$ C_{L_2} = -0.0686/1852 $$

$$ 0.0203 \delta \delta^o = -37 $$

$$ \delta^o = -18.23 $$
Obviously such a flap deflection defeats the purpose of the camber provided for high speed and would have a disastrous effect upon the low speed cavitation performance. Minimization of this adverse effect would require impractically large flap chord ratios and/or ineffectively small cambers.

In summary, the employment of flaps to eliminate the q term of the hinge moment requires a fixed flap angle and therefore a reflexed section would be employed rather than a flap. Evaluation of one particular flap case, as an approximation for the reflexed section, indicates that the cavitation effect is so negative as not to justify further investigation in the time available.
RATIONAL CONSIDERATION OF HINGE MOMENT CONTROL

Where flaps are employed for moment control, it is the hinge position of the first term of Eq. (10) and the flap schedule of the third term which are juggled to produce the optimum result. The second term is a fixed (by craft geometry) component of the zero speed hinge moment intercept. The last term is the basic slope term and is considered fixed by craft geometry in these analyses though in the distant future, when these terms are known with much better precision, the section camber may also be employed as an optimization variable. Only the infinite and one chord depth slopes, $C_{L}/C_{L_{\infty}}$, are considered here for the fourth term.

In general, the moment curve has the appearance:

These generalized characteristics determine the conditions which govern optimization for the three cases considered.
The craft weight will vary between extremes presented by the minimum flight weight at the maximum negative normal acceleration margin and the maximum flight weight at the maximum positive acceleration margin. To represent these extreme foil loadings it is convenient to define the parameter, $K$:

$$K = \frac{(\frac{W}{S})_{\text{max}} - (\frac{W}{S})_{\text{min}}}{2(\frac{W}{S})_{m}} = \frac{(\frac{W}{S})_{\text{max}} - (\frac{W}{S})_{\text{min}}}{(\frac{W}{S})_{\text{max}} + (\frac{W}{S})_{\text{min}}},$$

where: $(\frac{W}{S})_{\text{max}} = (1 + \Delta n)(\frac{W}{S})_{\text{nom. max}}$

$(\frac{W}{S})_{\text{min}} = (1 - \Delta n)(\frac{W}{S})_{\text{nom. min}}$

$(\frac{W}{S})_{m} = \frac{1}{2} \left[ (\frac{W}{S})_{\text{max}} + (\frac{W}{S})_{\text{min}} \right]$

For example, this note employs for the AG(EH) fwd foils:

$$\frac{W}{S}_{\text{max}} = \frac{1}{4} \times 1435 = 359.5$$

$$\frac{W}{S}_{\text{min}} = \frac{3}{4} \times 1220 = 915$$

$$\frac{W}{S}_{m} = \frac{359.5 + 915}{2} = \frac{2710}{2} = 1355$$

$$K = \frac{359.5 - 915}{2710} = \frac{880}{2710} = 0.325$$
\[ (41) \quad (\frac{W}{S})_{\text{max/min}} = (1 \pm K)(\frac{W}{S})_M \]

**MINIMUM HINGE MOMENT**

Referring to Eq. (10) the incidence hinge moments are minimized by setting:

\[ \left( \frac{H}{S \text{MAC}} \right) M_{\text{min}} + K, \frac{dH}{dc} = 1 + \left( \frac{H}{S \text{MAC}} \right) M_{\text{max}}, -K, \frac{dH}{dc} = \infty = 0 \]

\[ (43) \quad C_{Hc,0} (1 + K) \left( \frac{W}{S} \right)_M + \beta - \Delta \left( \frac{W}{S} \right)_S g_{\text{min}} + \frac{C_{d,0}}{C_{d,0} + C_{1,0}} C_{Hc,0} \frac{dH}{dc} = 0 \]

\[ 2 C_{Hc,0} \left( \frac{W}{S} \right)_M + 2 \beta - \Delta \left[ \left( \frac{W}{S} \right)_S g_{\text{min}} + \left( \frac{W}{S} \right)_S g_{\text{max}} \right] + C_{Hc,0} \left( \frac{C_{d,0} g_{\text{min}} + g_{\text{max}}}{C_{d,0} + C_{1,0}} \right) = 0 \]

\[ C_{Hc,0} \left( \frac{W}{S} \right)_M = \beta + \frac{1}{2} \left[ \left( \frac{W}{S} \right)_S g_{\text{min}} + \left( \frac{W}{S} \right)_S g_{\text{max}} \right] - \frac{1}{2} \left( \frac{C_{d,0}}{C_{d,0} + C_{1,0}} g_{\text{min}} + g_{\text{max}} \right) C_{Hc,0} \]

which locates the optimum hinge position when the flap schedule has been established.
The corresponding maximum hinge moment may be established either at \( q_{\text{max}} \) by substituting Eq. (43) into the appropriate form of Eq. (10). For the optimum hinge position and flag schedule the maximum hinge moment occurs at \( q_{\text{min}} \), where it is positive, and identically at \( q_{\text{max}} \), where it is negative. The absolute value of the maximum hinge moment is therefore given at \( q_{\text{min}} \),

\[
\frac{1}{\text{SMAC}} \frac{\partial m}{\partial q} = \left( \frac{H}{\text{SMAC}} \right) q_{\text{min}} + K, \quad M = 1
\]

\[
= \frac{(1+K)(\frac{W}{L})m}{(W/5)m} \left\{ -\beta + \frac{h}{2}(\frac{W}{3})q_{\text{min}} + (\frac{W}{3})q_{\text{max}} \right\} \\
\quad + \frac{h}{2} \left( \frac{\text{Cadic}}{\ell_{\text{doco}}} \frac{q_{\text{min}} + q_{\text{max}}}{C_{\text{HCO}_2=0}} \right) \\
= (1-1-K)\beta - \left\{ \left( \frac{W}{3} \right)q_{\text{min}} - \frac{h}{2}(1+K)\left[ \left( \frac{W}{3} \right)q_{\text{min}} + (\frac{W}{3})q_{\text{max}} \right] \right\} \\
\quad + \left[ \frac{\text{Cadic}}{\ell_{\text{doco}}} q_{\text{min}} - \frac{h}{2}(1+K)\left( \frac{\text{Cadic}}{\ell_{\text{doco}}} q_{\text{min}} + q_{\text{max}} \right) \right] C_{\text{HCO}_2=0}
\]

\[
= -K\beta - \left[ \frac{1}{2}(1-K)(\frac{W}{3})q_{\text{min}} - \frac{1}{2}(1+K)(\frac{W}{3})q_{\text{max}} \right] \\
\quad + \left[ \frac{1}{2}(1-K)\frac{\text{Cadic}}{\ell_{\text{doco}}} q_{\text{min}} - \frac{1}{2}(1+K)q_{\text{max}} \right] C_{\text{HCO}_2=0}
\]

\[
= -K\beta - \frac{1}{2} \left[ (1-K)(\frac{W}{3})q_{\text{min}} - (1+K)(\frac{W}{3})q_{\text{max}} \right] \\
\quad - \frac{1}{2} \left[ (1+K)q_{\text{max}} - (1-K)\frac{\text{Cadic}}{\ell_{\text{doco}}} q_{\text{min}} \right] C_{\text{HCO}_2=0}
\]
The first term is a minor adjustment for buoyancy. The zero lift hinge moment coefficient of the third term is negative so the third term is positive. Thus the maximum hinge moment is reduced by increasing the minimum speed flap angle and by reducing the maximum speed flap angle, No limit upon these foil loadings is presented by Eq. (44) except as to their relative value, or slope, as discussed below. There are practical limitations upon the flap angles however. Large flap angles present practical design problems and linearity effects which are not considered in this note. A $+30^\circ$ flap angle limit is assumed in this note. The high speed flap angle, which can be negative, is limited by the compromises one cares to take on the cavitation bucket.
Eq. (44) can be written in a form which emphasizes the effect of $K$ upon the maximum hinge moment and the fact that the unflapped foil is a degenerate special case of the equation:

\[
\frac{H_{\text{max}}}{\text{SMAC}} = -K \beta \\
\quad - \frac{1}{2} \left[ \frac{1}{\Delta \rho_0} \left( \frac{C_{\text{max}}}{\text{SMAC}} - \frac{C_{\text{min}}}{\text{SMAC}} \right) \right] \left( \frac{C_{\text{max}}}{\text{SMAC}} + \frac{C_{\text{min}}}{\text{SMAC}} \right) \\
\quad - \frac{1}{2} \Delta \left( \left[ \frac{1}{2} C_{\text{min}} - \left( \frac{1}{3} \right) C_{\text{max}} \right] - \left[ \frac{1}{2} C_{\text{min}} + \left( \frac{1}{3} \right) C_{\text{max}} \right] \right) \\
\]

Note that the speed range and the weight range both contribute to the maximum hinge moment for the unflapped foil. Provision of flaps can eliminate the effect of the speed range but not the effect of the weight range; nearly all of the maximum hinge moment for the flapped foil which has been optimized for moments is due to the weight range with the remainder being due to provision for limited depth. Thus a craft designed for platforming operation at a fixed weight could be provided with a zero moment system. On the other hand, the very long ranges now being considered would present relatively high hinge moments for an incidence-lift control system. Note, too, that the final term means that flaps do not necessarily reduce the maximum hinge moment.
Increasing the minimum speed flap angle and reducing the maximum speed flap angle reduces the moment slope. When the chord depth slope vanishes, Eq. (43) becomes invalid and must be redefined. Further changes in the flap schedule produce a positive chord depth moment slope and a zero infinite depth slope; then further changes make both slopes positive. It is in this region that the flap schedule begins to compromise the cavitation bucket and the optimum flap schedule is ultimately a subject of judgment of that compromise.

In order to provide a well defined "optimum" flap schedule for moments for this note, the optimum flap schedule is defined to have a slope which makes the infinite depth hinge moment slope vanish; i.e.,

$$\frac{d(H_{inf})}{dq} = -\Delta \frac{d\left(\frac{d^2}{dq^2}\right)}{dq} \cdot \frac{C_{L_d}}{C_{L_{in}}(z)} = 0$$

and this slope is passed through a $30^\circ$ flap angle at $q_{\min}$. This is the "optimum moment" flap schedule of Eqs. (36) and (37) and of Figure 13. It will be recognized that the chord depth slope could have been made to vanish or that the chord and infinite depth slopes could have been assigned equal values of opposite sign, which would have produced a still lower $H_{max}$. The definition adopted here is entirely arbitrary.
For this case Eq. (10) may be modified to (employing primes to indicate a restricted case):

\[
\frac{H_{1\text{MAC}}}{5\text{MAC}} = C_{H_L} \frac{W}{5} + \beta - \Delta \left[ \left( \frac{W}{5} \right) s_{g_{\text{max}}} + \frac{d \left( \frac{W}{5} \right)}{dp} \Delta g \right] + \frac{\Gamma_{c' L}}{\Gamma_{c' L}^0} \chi_{c' c = 0} \chi
\]

\[
= C_{H_L} \frac{W}{5} + \beta - \Delta \left( \frac{W}{5} \right) s_{g_{\text{max}}} + \frac{\chi_{c' c = 0}^0 \chi_{c' c = 0}}{\chi_{c' c = 0}} \Delta g + \frac{\Gamma_{c' L}}{\Gamma_{c' L}^0} \chi_{c' c = 0} \chi
\]

\[
= C_{H_L} \frac{W}{5} + \beta - \Delta \left( \frac{W}{5} \right) s_{g_{\text{max}}} + \chi_{c' c = 0}^0 \Delta g_{\text{max}} - \chi_{c' c = 0}^1 \chi + \frac{\Gamma_{c' L}}{\Gamma_{c' L}^0} \chi_{c' c = 0} \chi
\]

\[
= C_{H_L} \frac{W}{5} + \beta - \Delta \left( \frac{W}{5} \right) s_{g_{\text{max}}} + \chi_{c' c = 0}^0 \Delta g_{\text{max}} - \left( 1 - \frac{\Gamma_{c' L}}{\Gamma_{c' L}^0} \right) \chi_{c' c = 0} \chi
\]
The corresponding maximum hinge moment is minimized by setting:

\[(1 + \kappa)\left(\frac{\omega}{s}\right) \frac{\partial}{\partial \kappa} \left[ (\frac{\kappa^2}{s}) \right] \delta_{\max} + \kappa \frac{\delta}{\kappa} = 1 + \left(\frac{\kappa^2}{s} \frac{\partial}{\partial \kappa} \right) \delta_{\max} \right]_{\kappa = 1}^{\kappa = \infty} = 0\]

\[c_{H_0} (1 + \kappa) \left(\frac{\omega}{s}\right) \delta_{\max} + c_{H_2} \delta_{\max} - \left(1 - \frac{c_{H_2}}{c_{H_0}}\right) c_{H_2} \delta_{\max} = 0\]

\[c_{H_0} (1 - \kappa) \left(\frac{\omega}{s}\right) \delta_{\max} + c_{H_2} \delta_{\max} = 0\]

\[2 c_{H_0} \left(\frac{\omega}{s}\right) \delta_{\max} + 2 \beta - 2 \Delta \left(\frac{\omega}{s}\right) \delta_{\max} + \left(1 + \frac{c_{H_2}}{c_{H_0}}\right) c_{H_2} \delta_{\max} = 0\]

\[c_{H_0} \left(\frac{\omega}{s}\right) \delta_{\max} = -\beta + \Delta \left(\frac{\omega}{s}\right) \delta_{\max} - \frac{1}{2} \left(1 + \frac{c_{H_2}}{c_{H_0}}\right) c_{H_2} \delta_{\max}\]

For this hinge position in Eq. (47):
The bracketed term vanishes for a zero weight spread and the second
term vanishes for deep depth operation; i.e. this result presents analyti-
cally the condition for which a zero moment can be designed.
Eq. \((49)\) can be made to vanish for the general case with a sufficiently low top speed flap foil loading \((\sim = 2300 \text{ psf} \text{ for the AG(EH)})\) but this approach is back to the reflexed foil case and presents an intolerable compromise of the cavitation bucket. Therefore Eq. \((49)\) only says that the maximum speed flap foil loading should be as low as one's judgement of the cavitation effect will allow.

\[
\begin{align*}
(w/s)_{5} & \quad (w/s)_{4}^{\text{max}} \\
(\frac{w}{s})_{6}^{\text{min}} & \quad (\frac{w}{s})_{7}^{\text{max}}
\end{align*}
\]

Solid schedules are safe. Dashed schedule invites excessive hinge moment at extreme speeds.

Just as there is no well defined optimum flap foil loading for minimum or maximum speed, there is no optimum flap schedule connecting those points. Some care must be exercised at the two speed extremes to avoid producing hinge moments in excess of the moments at those extremes, which are presumably design values, but the flap schedule at intermediate speeds is completely arbitrary.
The three flap schedules of Figure 13 are evaluated for moments in this note. It is evident on Figure 13 that the optimum moment schedule compromises the unflapped cavitation bucket for q's above 6750 psf (48.7 knots) and that it compromises the optimum cavitation bucket for q's below 4130 psf (38 knots). These compromises may be seen on Figure 17. That at 48.7 knots is obviously insignificant and that at 38 knots is considered insignificant for reasons already presented in the discussion of Figure 17.

The moments for the three flap schedules of Figure 13, hinged to present minimum moments, are presented on Figure 18. Note that the optimum cavitation flap schedule has slightly increased the maximum moment of the unflapped foil, a result of the large weight and normal acceleration spread relative to the flap displacement spread (see the last term of Eq. (45)).

It is to be noted that the optimum moment \( H_{\text{max}} \) is 50% larger than the \( \frac{1}{4} K \frac{W}{S} m \) which intuitive consideration would lead us to hope for. The \( H_{\text{max}} \) is reduced by reducing the section \( c_{\text{Mac}} \) which requires a reduction in camber and/or the adoption of a camber line offering a more favorable \( c_{\text{Mac}} \).

Centering the moments in the zero axis has substantially reduced the maximum hinge moments but 'they are still probably too large to insure a slop-free system at crossover. It is not likely that any special purpose application will ever present itself offering sufficiently restricted weight and normal acceleration ranges for the confident specification of the minimum moment geometry.
MINIMUM NEGATIVE HINGE MOMENT

For this case Eq. (10) provides a hinge position for which the moment vanishes at

\[ \frac{H}{S_{MAC}} = 0 = \left( \frac{H}{S_{MAC}} \right) q_{\min} + K_1 d/C = 1 \]

\[ c_{H\alpha} (1 + K) \left( \frac{w}{s} \right) m + \beta - \Delta \left( \frac{w}{s} \right) s_{\min} + \frac{c_{ad} \Delta e - c_{H\alpha 0}}{c_{ad} + c_{H\alpha 0}} q_{\min} \]

\[ c_{H\alpha} (1 + K) \left( \frac{w}{s} \right) m = -\beta + \Delta \left( \frac{w}{s} \right) s_{\min} - \frac{c_{ad} \Delta e - c_{H\alpha 0}}{c_{ad} + c_{H\alpha 0}} q_{\min} \]

The maximum moment employs this hinge in a second application of Eq. (10):
\[\frac{H_{\text{max}}}{\text{MAC}} = \left(\frac{H}{\text{MAC}}\right)_{\text{MAC}} \cdot \frac{1}{H} \cdot \frac{1}{\text{MAC}} \cdot \frac{1}{H} \cdot H' \cdot H = 0\]

\[= \frac{1}{1+K} \left\{ -\beta + \Delta \left(\frac{w}{s}\right) s_{\text{min}} - \frac{C_{\text{max}}}{C_{\text{min}}} C_{\text{max}} \cdot s_{\text{max}} \right\} \]

\[+ \frac{1}{1+K} \Delta \left(\frac{w}{s}\right) s_{\text{max}} + \frac{1}{1+K} C_{\text{max}} \cdot s_{\text{max}} \]

\[ = (1 - \frac{1}{1+K}) \beta + \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[+ \left( \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} - \frac{1}{1+K} \right) \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} = 0\]

\[\frac{H_{\text{max}}}{\text{MAC}} = \left(\frac{1}{1+K} - 1\right) \beta - \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[- \left( \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} - \frac{1}{1+K} \right) \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} = 0\]

\[= - \frac{2K}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta - \left( \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} - \frac{1}{1+K} \right) \frac{C_{\text{max}}}{C_{\text{min}}} \cdot s_{\text{max}} \]

\[= \frac{1}{1+K} \left\{ -2K \beta - \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \right\} \]

\[= \frac{1}{1+K} \left\{ -2K \beta - \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \right\} \]

\[= \frac{1}{1+K} \left\{ -2K \beta - \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \right\} \]

\[= \frac{1}{1+K} \left\{ -2K \beta - \left[ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \right\} \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]

\[= \frac{1}{1+K} \left\{ \frac{1}{1+K} \left(\frac{w}{s}\right) s_{\text{min}} - \left(\frac{w}{s}\right) s_{\text{max}} \right\} \Delta + K \left[ \left(\frac{w}{s}\right) s_{\text{min}} + \left(\frac{w}{s}\right) s_{\text{max}} \right] \Delta \]
Eq. (51) is identical in form with Eq. (45) and, in fact, can be written:

\[
\left(\frac{|H_{\text{max}}|}{\text{SMAC}}\right)_{\text{min. neg. mom.}} = \frac{2}{1+k} \left(\frac{|H_{\text{max}}|}{\text{SMAC}}\right)_{\text{min. mom.}}
\]

Therefore all of the comment with regard to optimization and flap schedules of the minimum moment case apply to the minimum negative moment case. The only difference is that one extreme speed presents a zero hinge moment in this case, with potential crossover for careless flap management, and the other extreme speed presents the maximum, or design, hinge moment. For the previous, minimum moment, case both extreme speeds presented the maximum moment.
For the "optimum" moment case, having a zero infinite depth moment slope, the hinge must be set by evaluating Eq. (47) as:

\[
\left( \frac{H'}{\text{SMAC}} \right)_\text{max}, + H, dN = 0
\]

\[
C_{Hc} (1+K)(\frac{W}{S})m + \beta - \Delta (\frac{W}{S})S^\text{max} + C_{Hc2=0} S^\text{max} - (1 - \frac{C_{Hc2=0}}{C_{Hc2=0}}) S^\text{max} = 0
\]

\[
C_{Hc} (1+K)(\frac{W}{S})m = -\beta + \Delta (\frac{W}{S})S^\text{max} - \frac{C_{Hc2=0}}{C_{Hc2=0}} C_{Hc2=0} S^\text{max}
\]

The maximum moment is provided by employing this hinge position in Eq. (47) evaluated as:

\[
- \frac{1}{\text{SMAC}} \frac{H'_{\text{max}}}{H'_{\text{max}}} = (\frac{H'}{\text{SMAC}})_\text{max}, - H, dN = \infty
\]

\[
= \frac{1 - H}{1 + H} \left\{ -\beta + \Delta (\frac{W}{S})S^\text{max} - \frac{C_{Hc2=0}}{C_{Hc2=0}} C_{Hc2=0} S^\text{max} \right\}
\]

\[
+ \beta - \Delta (\frac{W}{S})S^\text{max} + C_{Hc2=0} S^\text{max}
\]

\[
= (1 - \frac{H}{1 + H})\beta + (\frac{H}{1 + H} - 1)\Delta (\frac{W}{S})S^\text{max} + (1 - \frac{H}{1 + H} \frac{C_{Hc2=0}}{C_{Hc2=0}}) C_{Hc2=0} S^\text{max}
\]

\[
\frac{H'_{\text{max}}}{\text{SMAC}} = - \frac{2K}{1 + H} \beta + \frac{2K}{1 + H} \Delta (\frac{W}{S})S^\text{max} - (1 - \frac{H}{1 + H} \frac{C_{Hc2=0}}{C_{Hc2=0}}) C_{Hc2=0} S^\text{max}
\]

\[
= \frac{2}{1 + H} \left\{ H [-\beta + \Delta (\frac{W}{S})S^\text{max}] - \frac{1 + H}{2} (1 - \frac{H}{1 + H} \frac{C_{Hc2=0}}{C_{Hc2=0}}) C_{Hc2=0} S^\text{max} \right\}
\]
The third term will transform into:

\[ -\frac{1+H}{2} (1-\frac{1-H}{1+H})G_{\text{G2C6}} = \frac{1}{2} (1+H) + \frac{1}{2} (1-H) \left( \frac{c_{\text{C2G2C6}}}{c_{\text{C2G2C6}}} \right) G_{\text{G2C6}} \]

Then Eq. (54) may be written:

\[ \left( \frac{1}{s_{\text{MAC}}} \right)_{\text{max}} = \frac{2}{1+H} \left( \frac{1}{s_{\text{MAC}}} \right)_{\text{min. neg. mom.}} \]

which is identical with Eq. (52) so the optimum negative moment case is simply a special case of the minimum negative moment general case.
The moments for the three flap schedules of Figure 13, hinged to present negative moments for all flight conditions, are presented on Figure 19. **The unflapped result of Figure 19 differs slightly from that of Figure 6 of Reference 1 because the hinge has been moved slightly in this note to produce a zero minimum hinge moment.**
For this case Eq. (10) provides a hinge position for which the moment vanishes at:

\[
\frac{H}{S_{MAC}} = 0 = \left(\frac{H}{S_{MAC}}\right) g_{\text{max}} - K_3 \frac{d}{c} = 0
\]

\[
= C_{MC_2} (1-K) \left(\frac{w}{2}\right) m + \beta - \Delta \left(\frac{w}{3}\right) g_{\text{max}} + C_{MC_2} = 0
\]

\[
C_{MC_2} (1-K) \left(\frac{w}{2}\right) m = -\beta + \Delta \left(\frac{w}{3}\right) g_{\text{max}} - C_{MC_2} g_{\text{max}}
\]

The maximum moment employs this hinge in a second application of Eq. (10):
This equation is identical in form with one appearing in the development of Eq. (51) and may be written:
For the optimum moment case, having a zero infinite depth moment slope, the hinge must be set by evaluating Eq. (47) as:

\[
\frac{H_{\text{max}}}{S_{\text{MAC}}} \left( \frac{\gamma_{\text{min}, \text{pos. mom.}}}{\gamma_{\text{min}, \text{mom.}}} = \frac{2}{1-K} \frac{H_{\text{max}}}{S_{\text{MAC}}} \right)
\]

\[+K, \quad dN = 1\]

\[-K, \quad dN = \infty\]

\[\gamma_{\text{min.}} \quad \gamma_{\text{max.}}\]

\[
\frac{H_{\text{max}}}{S_{\text{MAC}}} \left( \frac{\gamma_{\text{min}, \text{pos. mom.}}}{\gamma_{\text{min}, \text{mom.}}} = \frac{2}{1-K} \frac{H_{\text{max}}}{S_{\text{MAC}}} \right)
\]

The maximum moment is provided by employing this hinge position in Eq. (47) evaluated as:
and by reference to Eq. (54) this may be written:

\[
\left(\frac{H_{\text{max}}}{\text{SMAC}}\right)_{\min, \text{pos. mom.}} = \frac{2}{1-K} \left(\frac{H_{\text{max}}}{\text{SMAC}}\right)_{\text{min. mom.}}
\]

which is identical with Eq. (60).

The moments for the three flap schedules of Figure 13, hinged to present positive moments for all flight conditions, are presented on Figure 20.
FLAP CAVITATION AND MOMENT CONTROL SUMMARY

The hinge location equations are summarized in Table V and the corresponding maximum hinge moment equations are summarized in Table VI. Expression of the numerical results of this note in terms of $H/SMAC$ insures that the results are characteristic of any size craft. The $AG(EH)$ camber, and these numerical results, are characteristic of any craft of design top speed less than 50-60 knots.

Referring to the optimum maximum moment equation of Table VI it is evident that the zero hinge moment incidence lift control foil does exist, but only if the following explicit restrictions on the operating conditions can be observed:

1. No variation in craft weight of $C_G$, (zero fuel consumption) (for $K = 0$), and
2. Platforming operation ($A_n = 0$ for $K = 0$), and
3. Operation at a constant depth (to make the final term vanish),

and if the following implicit conditions are satisfied,

4. Aerodynamic center prediction is perfect, and
5. Residual pitching moment prediction is perfect, and
6. Flap hinge moment derivative, $\Delta$, prediction is perfect
Violation of each of these six conditions is associated with an increment of maximum hinge moment and conversely, approaching each of those six conditions reduces the maximum hinge moment.

The numerical results for the $AG(EH)$ are summarized in Table VII and lead to the following conclusions. These numerical results are strongly influenced by $K$ but the $AG(EH)$ is typical for this factor.

It is not likely that any design objective will be sufficiently restricted to allow use of the minimum moments. Flaps are about twice as high as negative moments, therefore the negative moment hinge position will probably be employed on all incidence Bilt systems.

Flaps can reduce the limit hinge moment by some $40\%$. Flaps can also increase the hinge moment, of course, but only through careless scheduling. One decided current advantage of flaps is that they can be employed to correct for design errors; i.e., to eliminate crossover or reduce excessive moments caused by faulty hinging.

Flaps can be employed to shape the cavitation bucket but this is a sophisticated technique requiring knowledge of the effective cavitation boundaries which is totally lacking now.

As a still more sophisticated use of flaps to shape the cavitation bucket, it appears that the speed range of the conventional section could be extended to something of the order of 80 knots, cavitation free, by flaps. The transit foil employs a conventional section in this speed range but with significant cavitation.
THE "FLYING" FOIL

The "flying" foil is defined here to be an incidence lift control foil which is freely pivoted about the incidence axis and which carries an incidence control, trailing edge flap,

In coefficient form Eq. (10) reads:

\[
\frac{H}{S M A C} = C_{H c L} \frac{W}{S} + \beta - \Delta (\frac{W}{S}) \delta + \frac{C_{L}^{2} \alpha}{C_{L_{\infty}}} C_{H c c_{\alpha}} \delta \\
C_{H} = \frac{H}{S M A C} \beta = C_{H c L} C_{L} + \frac{\beta}{\delta} - \Delta (C_{L}) \delta + \frac{C_{L}^{2} \alpha}{C_{L_{\infty}}} C_{H c c_{\alpha}} \delta
\]

having the derivative:

\[
\frac{dC_{H}}{dC_{L}} = C_{H c L}
\]

The flying foil, then, requires a negative \( C_{H c L} \); i.e., the incidence hinge is ahead of the aerodynamic center,

The flying foil trims at an angle defined by
The desirable value for $C_{HC_L}$ is a dynamic problem which would have to be examined on SLOCCOP but that value has a cavitation significance which can be examined here.
Eq. (66) may be written:

\[
\frac{W}{S} = C_L \rho = \frac{1}{C_{H_C}} \left[ - \beta + \Delta \left( \frac{W}{S} \right)_S - \frac{C_{Ld}}{C_{L_{\infty}}} C_{H_{C_{\infty}}} \rho \right]
\]

\[
\Delta \left( \frac{W}{S} \right)_S = C_{H_C} \frac{W}{S} + \beta + \frac{C_{Ld}}{C_{L_{\infty}}} C_{H_{C_{\infty}}} \rho
\]

\[
\left( \frac{W}{S} \right)_S = \frac{1}{\Lambda} \left[ C_{H_C} \frac{W}{S} + \beta + \frac{C_{Ld}}{C_{L_{\infty}}} C_{H_{C_{\infty}}} \rho \right]
\]

For the AG(EH) fwd foils at infinite depth this evaluated to:

\[
\left( \frac{W}{S} \right)_S = \frac{1}{\Lambda} \left( C_{H_C} \frac{W}{S} + \beta \right) - \frac{0.0856}{105} \rho
\]

\[
= \frac{1}{\Lambda} \left( C_{H_C} \frac{W}{S} + \beta \right) - 0.37 \rho
\]

At 50 knots this requires a \( \frac{W}{S} \) of some -2600 psf at 50 knots just for the \( q \) term; the first two terms are also negative. This is sufficient demonstration of the infeasibility of the trailing edge flap as a control device for the flying foil.
It must be noted that the discussion is limited to consideration of the trailing edge flap controlled flying foil. There is an arrangement of the flying foil that is entirely feasible hydrodynamically though it has not yet been examined mechanically:

The flying foil is deserving of serious consideration because it relieves the autopilot of the problem of cancelling the orbital angle of attack and because it might incorporate some depth sensitivity. The arrangement presents formidable dynamic analytical problems. The SLOCOP program now makes it possible to evaluate this arrangement and its detailed consideration is recommended.
REFERENCES


<table>
<thead>
<tr>
<th>$c_s$</th>
<th>$C_l$</th>
<th>$C_{l/2}$</th>
<th>$C_{l/2}$</th>
<th>$C_{l/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_l$</td>
<td>$C_{l/2}$</td>
<td>$C_{l/2}$</td>
<td>$C_{l/2}$</td>
<td>$C_{l/2}$</td>
</tr>
</tbody>
</table>

### Symbols

- $C_l$: Lift coefficient
- $C_{l/2}$: Half-chord lift coefficient
- $C_{l/2}$: Half-span lift coefficient
- $C_s$: Spanwise chord variation
- $C_t$: Thrust coefficient

### Notes

1. All dimensions in ft$^2$/sec, unless otherwise noted.
2. Flap deflection is due to elevator, unless noted.
3. Measured in plane perpendicular to quarter-chord.

### Additional Notes

- $C_l = C_{l/2}$ for pitch or incidence lift.
- The two are practically the same for the actual fraction of MAC.
- Chord usually MAC.

### Aeronautical Center

- Subscript indicates which wing.
- The moment is about the quarter-chord.

### BUOYANCY CENTER

- Fraction of MAC.
- $C_{l/2}$ usually MAC.
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C_{l_{d}}$</td>
<td>Additional (type) lift distribution (on chord) due to flap.</td>
</tr>
<tr>
<td>$C_{l_{b}}$</td>
<td>Basic (type) lift distribution (on chord) due to flap.</td>
</tr>
<tr>
<td>$C_{m_{a,c}}$</td>
<td>Section moment coefficient about $x_c$, for 15-series section $x_c$, appears to be $1 / 4$ with $C_{m_{a,c}} = \frac{1}{4} C_{l_{b}}' \text{chord}$ ($x_{c} = 10 \text{ chord line}$).</td>
</tr>
<tr>
<td>$C_{P_{b}}$</td>
<td>Center of pressure, fraction of MAC.</td>
</tr>
<tr>
<td>$d_{a}$</td>
<td>Depth, identical with $d$.</td>
</tr>
<tr>
<td>$d_{a/h}$</td>
<td>Flap effectiveness.</td>
</tr>
<tr>
<td>$G_{*}$</td>
<td>Allen's centroid for flap basic load distribution referenced to $C/4$ and expressed as fraction of chord. * indicates absolute value to avoid assigning sign to a distance.</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>Acceleration of gravity.</td>
</tr>
<tr>
<td>$H$</td>
<td>Incidence hinge moment positive nose up.</td>
</tr>
<tr>
<td>$H'$</td>
<td>Minimum hinge moment. $\frac{d}{dH}$ $H_{1.0} = 0$.</td>
</tr>
<tr>
<td>$H_{c}$</td>
<td>Incidence hinge position, fraction of MAC.</td>
</tr>
<tr>
<td>$H_{b}$</td>
<td>Buoyant hinge moment, $B_{MAC} (\frac{1}{4} - b_{c})$.</td>
</tr>
<tr>
<td>$H_{c}$</td>
<td>Depth, identical with $d$.</td>
</tr>
<tr>
<td>$h_{i}$</td>
<td>Incidence angle.</td>
</tr>
<tr>
<td>$K$</td>
<td>$[\frac{(h_{i})<em>{MAC} - (h</em>{i})<em>{MIN}}{h</em>{i}}] \text{chord}$, similar to $h_{i}$ but including accountability for range in flight weight &amp; CG.</td>
</tr>
<tr>
<td>$L$</td>
<td>Lift, positive up.</td>
</tr>
<tr>
<td>$MAC$</td>
<td>Mean aerodynamic chord.</td>
</tr>
<tr>
<td>$\Delta N$</td>
<td>Normal acceleration margin for negotiating seas, nominal value of $\pm 1 / 4 g$ assumed here.</td>
</tr>
<tr>
<td>$P_{a}$</td>
<td>Atmospheric pressure. This note employs $P_{a} - P_{v} = 2044$ psf.</td>
</tr>
<tr>
<td>$P_{v}$</td>
<td>Vapor pressure, see $P_{a}$.</td>
</tr>
<tr>
<td>$q$</td>
<td>Dynamic pressure, $2.84 \text{ Vh}^2$ psf.</td>
</tr>
<tr>
<td>$S$</td>
<td>Foil area or local pressure coefficient, see Eqs. (12) &amp; (20).</td>
</tr>
<tr>
<td>$T_{c}$, $T_{10}$</td>
<td>Theodorsen coefficients, $T_{10}/V_{c}$ is theoretical $dL/dS$.</td>
</tr>
<tr>
<td>$V_{C}$</td>
<td>Speed.</td>
</tr>
<tr>
<td>$V_{C0}$</td>
<td>Cavitation speed.</td>
</tr>
<tr>
<td>$V_{C}$</td>
<td>Cavitation speed for zero depth (a mathematical concept, speed in knots).</td>
</tr>
<tr>
<td>Symbol</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>$\frac{V}{V}$</td>
<td>Local velocity ratio (on chord) due to thickness distribution.</td>
</tr>
<tr>
<td>$\frac{\Delta V}{V}$</td>
<td>Local velocity ratio increment due to camber (distribution on chord for $C_l^{app.}$).</td>
</tr>
<tr>
<td>$\frac{\Delta V}{V}$</td>
<td>Local velocity ratio increment due to flap basic (type) load, per unit $C_l^0$.</td>
</tr>
<tr>
<td>$\frac{\Delta V}{V}$</td>
<td>Local velocity ratio increment of additional load type, due to angle of attack and/or flap deflection, per unit $C_l^0$ increment.</td>
</tr>
<tr>
<td>$\frac{(w/S)_b}{(w/S)_d}$</td>
<td>Total foil loading, $(w/S)_b + (w/S)_d + (w/S)_s$.</td>
</tr>
<tr>
<td>$C_l^0$</td>
<td>Buoyant foil loading, $B/S$.</td>
</tr>
<tr>
<td>$C_l^0$</td>
<td>Incidence foil loading, $C_l^0$.</td>
</tr>
<tr>
<td>$C_l^0$</td>
<td>Pitch foil loading, $C_l^0$.</td>
</tr>
<tr>
<td>$C_l^0$</td>
<td>Flap foil loading, $C_l^0$.</td>
</tr>
<tr>
<td>$C_l^0$</td>
<td>Mean foil loading, $[\frac{(w/S)<em>{max}}{2} + \frac{(w/S)</em>{min}}{2}]$. Where max, &amp; min, foil loadings account for flight weight &amp; balance range and for nominal normal acceleration requirements.</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>Angle of attack, total of geometric and dynamic components, not employed in this note.</td>
</tr>
<tr>
<td>$\beta$</td>
<td>A buoyant moment parameter, $(g_{bu} - g_{bc})(w/S)_B$.</td>
</tr>
<tr>
<td>$\Delta$</td>
<td>A flap chordwise lift distribution parameter, $= \frac{1}{4} (1 + \frac{\Delta \theta}{\Theta_{flap}})$ in this note (doubtful confidence level).</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Flap deflection, positive nose up.</td>
</tr>
<tr>
<td>$\sigma$</td>
<td>A flap chordwise lift distribution parameter, $= \frac{C_{l_{\theta}}}{C_l}$ in this note (doubtful confidence level).</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Craft pitch angle, positive bow up.</td>
</tr>
<tr>
<td>$C_{l_{\sigma}}$</td>
<td>A spanwise load distribution parameter, $\frac{(g/I)(\sigma)}{(g/I)(\beta)} - 1$.</td>
</tr>
<tr>
<td>$C_{l_{\eta}}$</td>
<td>A spanwise load distribution parameter, $\frac{(g/I)(\eta)}{(g/I)(\beta)} - 1$.</td>
</tr>
<tr>
<td>$\rho$</td>
<td>Density, $1.0505 \frac{lbm}{ft^3}$ (slug/ft $^3$).</td>
</tr>
<tr>
<td>$N$</td>
<td>Cavitation number, $\frac{(P_0 - P_N + P_{gh})}{\rho}$.</td>
</tr>
</tbody>
</table>
SYMBOLS (CONT.)

\[ \psi \]
A CHORDWISE VELOCITY DISTRIBUTION PARAMETER,
\[ \frac{\Delta V}{V} \pm \frac{\Delta V}{V} \frac{\Delta V}{V} \left( \pm \text{UPPER SURFACE} \right) \frac{\Delta V}{V} \left( \pm \text{LOWER SURFACE} \right) \]

\[ \omega \]
A FLAP LOAD DISTRIBUTION PARAMETER,
\[ \psi \left[ \frac{\Delta V}{V} \right] - \frac{\Delta V}{V} \]

SUBSCRIPTS

B
DUE TO BUOYANCY

F
DUE TO FLAP DEFLECTION

H
HYDRODYNAMIC (EXCLUDING BUOYANCY)

I
DUE TO INCIDENCE

\[ \text{max} \]
MAXIMUM

\[ \text{min} \]
MINIMUM

\[ \text{nom} \]
NOMINAL

\[ \text{max}_{\text{F}} \]
AT MAXIMUM FLIGHT SPEED

\[ \text{min}_{\text{F}} \]
AT MINIMUM FLIGHT SPEED

\[ \alpha_{0} \]
AT ZERO SPEED (A MATHEMATICAL CONCEPT)

\[ \alpha \]
DUE TO PITCH LIFT (ANY CHANGE IN ANGLE OF ATTACK FOR FOIL AND POD)

\[ \psi \]
DUE TO FLAP DEFLECTION

\[ s \]
RESIDUAL, AT \( \alpha = \alpha' = \delta = 0 \)

\[ l_{c} \]
AT 1 MAC DEPTH

\[ \infty \]
AT INFINITE DEPTH (AERODYNAMIC)

\[ C_{vF} = (C_{v})_{i} + C_{l0} \]

\[ (\frac{\psi}{s})_{\text{ref}} = (\frac{\psi}{s})_{i} + (\frac{\psi}{s})_{0} \]

\[ = \left[ (C_{v})_{i} + C_{l0} \right] \phi \]
### Table I
**Cavitation Parameters**
AG(EH) FWD, FOIL MODEL

<table>
<thead>
<tr>
<th>STATION, %</th>
<th>1.25</th>
<th>2.5</th>
<th>5</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>V/V</td>
<td>1.025</td>
<td>1.051</td>
<td>1.060</td>
<td>1.083</td>
<td>1.092</td>
<td>1.088</td>
<td>1.067</td>
</tr>
<tr>
<td>( \frac{V}{V} \pm \Delta \frac{V}{V} )</td>
<td>1.098</td>
<td>1.124</td>
<td>1.133</td>
<td>1.161</td>
<td>1.165</td>
<td>1.161</td>
<td>1.140</td>
</tr>
<tr>
<td>( \Delta V_a/V )</td>
<td>0.552</td>
<td>0.978</td>
<td>0.987</td>
<td>1.015</td>
<td>1.012</td>
<td>1.015</td>
<td>0.994</td>
</tr>
<tr>
<td>( C_{i_{\text{eff}}} \frac{\Delta V_a}{V} )</td>
<td>0.394</td>
<td>0.284</td>
<td>0.201</td>
<td>0.047</td>
<td>0.038</td>
<td>0.030</td>
<td>0.022</td>
</tr>
<tr>
<td>( \Delta V )</td>
<td>1.704</td>
<td>1.840</td>
<td>1.932</td>
<td>1.114</td>
<td>1.127</td>
<td>1.131</td>
<td>1.118</td>
</tr>
<tr>
<td>( \Delta V \pm \Delta V )</td>
<td>1.346</td>
<td>1.262</td>
<td>1.188</td>
<td>1.062</td>
<td>1.057</td>
<td>1.045</td>
<td>1.016</td>
</tr>
</tbody>
</table>

\( \delta = (0.353) \delta \) SECTION

8.5 ft, & 9.33 ft, DEPTHS

\( \gamma = 2.84 V_{m} \)
\( \gamma' = 1.468 \gamma \)
\( \sigma_{1} = 2588/\gamma' + 26.41/\gamma' \)
\( (\frac{\gamma}{\gamma})_{b} = 90 \)

\( (\frac{\sigma}{\sigma})_{a} = \sigma_{a} 0.048 \gamma \) FOR 10@1MAC

UPPER NUMBER = OR SIGN IS UPPER SURFACE

\( \frac{(c_{f})}{(c_{L})} = 1.31 \)
\( (c_{f})_{s} = 0.109 \)
\( (c_{L})_{s} = +0.240 \)

\( C_{i_{\text{eff}}} = 0.83 \gamma \)
\( \Delta V/V = 0.25 C_{i_{\text{eff}}} = 0.073 \)
\( \gamma = \gamma \pm \Delta \gamma + C_{i_{\text{eff}}} \Delta V \)
### TABLE II
**Cavitation Parameters**

**AG(EH) FWD. FOIL PROTOTYPE**

<table>
<thead>
<tr>
<th>STATION, %</th>
<th>1.25</th>
<th>2.5</th>
<th>5</th>
<th>50</th>
<th>60</th>
<th>70</th>
<th>80</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V/V )</td>
<td>1.725</td>
<td>1.051</td>
<td>1.060</td>
<td>1.088</td>
<td>1.092</td>
<td>1.089</td>
<td>1.067</td>
</tr>
<tr>
<td>( \sqrt{V/V} \pm \Delta \sqrt{V/V} )</td>
<td>1.106</td>
<td>1.132</td>
<td>1.141</td>
<td>1.160</td>
<td>1.173</td>
<td>1.169</td>
<td>1.148</td>
</tr>
<tr>
<td>( \Delta V/V )</td>
<td>0.944</td>
<td>0.970</td>
<td>0.973</td>
<td>1.007</td>
<td>1.011</td>
<td>1.007</td>
<td>0.936</td>
</tr>
<tr>
<td>( C_l_{eff} \Delta V/V )</td>
<td>1.346</td>
<td>0.970</td>
<td>0.862</td>
<td>0.162</td>
<td>0.131</td>
<td>0.103</td>
<td>0.076</td>
</tr>
<tr>
<td>( \chi )</td>
<td>0.430</td>
<td>0.314</td>
<td>0.222</td>
<td>0.052</td>
<td>0.042</td>
<td>0.033</td>
<td>0.025</td>
</tr>
<tr>
<td>( (W/V_f) )</td>
<td>0.670</td>
<td>0.818</td>
<td>0.919</td>
<td>1.117</td>
<td>1.131</td>
<td>1.156</td>
<td>1.123</td>
</tr>
<tr>
<td>( \omega )</td>
<td>1.380</td>
<td>1.284</td>
<td>1.201</td>
<td>1.053</td>
<td>1.053</td>
<td>1.040</td>
<td>1.011</td>
</tr>
<tr>
<td>( \omega (s, 345) )</td>
<td>0.1725</td>
<td>0.354</td>
<td>0.352</td>
<td>-0.032</td>
<td>-0.083</td>
<td>-0.162</td>
<td>-0.552</td>
</tr>
<tr>
<td>( \omega (s, 346) )</td>
<td>1.620</td>
<td>1.439</td>
<td>1.301</td>
<td>-0.027</td>
<td>-0.071</td>
<td>-0.138</td>
<td>-0.477</td>
</tr>
</tbody>
</table>

16- (590) 08 SECTION
1 MAC (0.33 ft) DEPTH
20% CHORD FLAP
\( \chi = 2.84 \, V_h \)
\( \chi' = .648 \.chi \)
\( \chi' = 2.041/\chi \)

**UPPER NUMBER OR SIGN IS UPPER SURFACE**

\( \frac{\chi}{\chi'} \) \( s = \frac{\chi}{\chi'} \) \( v = 1.310 \)
\( \frac{\chi}{\chi'} \) \( s = \frac{\chi}{\chi'} \) \( v = .710 \)
\( \delta \) \( = -1.09 \)
\( \delta \) \( = +1.240 \)

\[ \Delta V/V = .25C_l_{eff} = .081 \]
\[ \chi = \sqrt{1 - \chi_{eff} \Delta V/V} \]
\[ \omega = s \left[ \frac{\Delta V/V}{V} - \left( \frac{\Delta V/V}{V} \right) _f \right] \]
TABLE III

OPTIMUM CAVITATION BUCKET

EFFECT OF S

<table>
<thead>
<tr>
<th>SECTION</th>
<th>(16-3.250)OB</th>
<th>(16-6.320)OB</th>
</tr>
</thead>
<tbody>
<tr>
<td>FLAP C</td>
<td>20%</td>
<td>20%</td>
</tr>
<tr>
<td>CHORD STA.</td>
<td>1.25%</td>
<td>80%</td>
</tr>
<tr>
<td>L/D</td>
<td>1.71</td>
<td>0.76</td>
</tr>
<tr>
<td>CA</td>
<td>1.295</td>
<td>1.295</td>
</tr>
<tr>
<td>Cx(V)</td>
<td>0.324</td>
<td>0.222</td>
</tr>
<tr>
<td>1/N+L/V</td>
<td>1.058</td>
<td>1.140</td>
</tr>
<tr>
<td>N</td>
<td>0.70</td>
<td>1.118</td>
</tr>
<tr>
<td>T4/V</td>
<td>-1.144</td>
<td>-5.498</td>
</tr>
<tr>
<td>T9/V</td>
<td>-2.55</td>
<td>0.741</td>
</tr>
<tr>
<td>T9/V</td>
<td>-2.55</td>
<td>0.741</td>
</tr>
<tr>
<td>1</td>
<td>-2.55</td>
<td>0.741</td>
</tr>
<tr>
<td>6'</td>
<td>-2.55</td>
<td>0.741</td>
</tr>
<tr>
<td>G</td>
<td>5.45</td>
<td>(SEE NOTE)</td>
</tr>
<tr>
<td>(526)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-5.39</td>
<td>-7.35</td>
</tr>
<tr>
<td>K</td>
<td>-5.39</td>
<td>-7.35</td>
</tr>
<tr>
<td>(c0/c)</td>
<td>1.310</td>
<td></td>
</tr>
<tr>
<td>(c0/c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(w/c)</td>
<td>0.588</td>
<td>0.588</td>
</tr>
<tr>
<td>(w/c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NOTES:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. ALL VELOCITY DISTRIBUTIONS ARE FOR UPSTREAM FLAP.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. 5.45 IS VALUE GIVEN S IN INTERIM REPORT FOR 20% C FLAP.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SEE TABLES I &amp; II FOR C1, C2, C3, C4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1/6' FROM TABLE 3.1, REF. 4.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G* FROM TABLE IV, REF. 5 FOR S = 5°, 10°, 15°.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S = D/G*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(c0/c)  = (c0)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[
K = -s \left[ 1 - \frac{(c0/c)}{c0/c} \right]
\]

\[
(c0/c) = (c0)^{-1}
\]

*REF 4
**TABLE IV**

**OPTIMUM CAVITATION BUCKET**

**EFFECT OF SECTION AND FLAP CHORD**

<table>
<thead>
<tr>
<th>SECTION</th>
<th>FLAP C</th>
<th>16-(390)08</th>
<th>16-008</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHORD STA.</td>
<td>16%</td>
<td>80%</td>
<td>125%</td>
</tr>
<tr>
<td>$c_{L_{reff}}$</td>
<td>1.34</td>
<td>0.07</td>
<td>1.34</td>
</tr>
<tr>
<td>$c_{D_{reff}}$</td>
<td>0.32</td>
<td>0.00</td>
<td>0.32</td>
</tr>
<tr>
<td>$c_{D}/c_{L_{reff}}$</td>
<td>0.43</td>
<td>0.02</td>
<td>0.43</td>
</tr>
<tr>
<td>$T_4/T_0$</td>
<td>1.10</td>
<td>1.14</td>
<td>1.10</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.67</td>
<td>1.13</td>
<td>0.67</td>
</tr>
<tr>
<td>$T_4/T_0$</td>
<td>-1.42</td>
<td>0.75</td>
<td>-1.42</td>
</tr>
<tr>
<td>$T_{4d}/T_0$</td>
<td>0.51</td>
<td>0.81</td>
<td>0.51</td>
</tr>
<tr>
<td>$T_{4d}/T_{0d}$</td>
<td>-0.25</td>
<td>-0.61</td>
<td>-0.25</td>
</tr>
<tr>
<td>$1+\frac{T_{4d}}{T_{0d}}$</td>
<td>0.74</td>
<td>0.33</td>
<td>0.74</td>
</tr>
<tr>
<td>$A$</td>
<td>0.18</td>
<td>0.07</td>
<td>0.18</td>
</tr>
<tr>
<td>$G^*$</td>
<td>0.29</td>
<td>0.24</td>
<td>0.29</td>
</tr>
<tr>
<td>$S$</td>
<td>0.46</td>
<td>0.41</td>
<td>0.46</td>
</tr>
<tr>
<td>$(AV/N)_E$</td>
<td>0.015</td>
<td>1.10</td>
<td>0.035</td>
</tr>
<tr>
<td>$(AV/N)_E(1+\gamma)$</td>
<td>0.0115</td>
<td>14.48</td>
<td>0.0260</td>
</tr>
<tr>
<td>$1-\frac{(AV/N)_E}{(AV/N)_E(1+\gamma)}$</td>
<td>0.8838</td>
<td>-13.48</td>
<td>0.774</td>
</tr>
<tr>
<td>$K$</td>
<td>-0.60</td>
<td>0.28</td>
<td>-0.60</td>
</tr>
<tr>
<td>$(G/A)^*_{S}$</td>
<td>1.31</td>
<td>0.2641</td>
<td>0.8975</td>
</tr>
<tr>
<td>$P_{a}-P_{v}+P_{gh}$</td>
<td>26.41</td>
<td>0.8975</td>
<td>0.90</td>
</tr>
<tr>
<td>$C_{a_2}$</td>
<td>0.0475</td>
<td>0.90</td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:** 1. All velocity distributions are for upstream surface.

**SEE TABLE II FOR $C_{a_{L_{reff}}}$**

$$\gamma = \frac{c_{L_{reff}} - c_{D_{reff}}}{c_{L_{reff}}}$$

**T4 $\div$ T0 FROM TABLE 3.1, REF. 4.**

**G* FROM TABLE IV, REF. 5 FOR $S = 5^\circ, 10^\circ, 15^\circ$.**

**S = A/G* $\downarrow$**

**$(AV/N)_E$ FROM FIG. 4.$\uparrow$**

$$K = -S\left[1 - \frac{(AV/N)_E}{(AV/N)_E(1+\gamma)}\right]$$

$(G/A)^*_{S}$ OF FIG. 6.1, REF. 4. **$P_{a}-P_{v}+P_{gh}$ FOR 9.33 ft. DEPTH $C_{a_2}$ FOR 1° $\theta$ @ 9.33 ft.**
<table>
<thead>
<tr>
<th></th>
<th>MINIMUM POSITIVE MOMENT</th>
<th>MINIMUM MOMENT</th>
<th>MINIMUM NEGATIVE MOMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAPPED</td>
<td>$\chi_{L} \left(1-K\right) \left(\frac{w}{5}\right) m = -\beta - \chi_{\alpha=0} \frac{g}{g_{\max}}$</td>
<td>$\chi_{L} \left(\frac{w}{5}\right) m = -\beta$</td>
<td>$\chi_{L} \left(1+K\right) \left(\frac{w}{5}\right) m = -\beta$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$\chi_{\alpha=0} \frac{g}{g_{\max}} \frac{C_{\alpha_{l}}}{C_{\alpha_{l0}}}$</td>
</tr>
<tr>
<td>LAPPED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAPPED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HUE &lt; 0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$+ \Delta \left(\frac{w}{5}\right) \frac{g}{g_{\max}}$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LAPPED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MINIMUM MOMENT</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\frac{dH}{d\alpha} \mid_{\alpha=0} = 0$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**NOTES:**
1. $\frac{H}{\alpha_{C}} = \chi_{L} + \alpha_{C}$
2. To suit operating limitations, substitute any lift curve slope (including 00) for $C_{\alpha_{l}}$. 

**TABLE V**
OPTIMUM HINGE LOCATIONS (FOR MINIMUM $|H_{\max}|$)
<table>
<thead>
<tr>
<th>Location</th>
<th>Minimum Positive Moment</th>
<th>Minimum Negative Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-FLAPPED</td>
<td>$\frac{H_{\text{max}}}{\text{SMAC}}$</td>
<td>$-K\beta$</td>
</tr>
<tr>
<td></td>
<td>$-\frac{1}{2}K\left(\frac{\gamma_{\text{max}}+\text{C_{d_{0}}}}{\text{C_{d_{0}a}}}-\gamma_{\text{in}}\right)$</td>
<td>$-\frac{1}{2}\left(\frac{\gamma_{\text{max}}-\text{C_{d_{0}}}}{\text{C_{d_{0}a}}}-\gamma_{\text{in}}\right)$</td>
</tr>
<tr>
<td>FLAPPED</td>
<td>$\frac{2}{1-K}\left(\frac{H_{\text{max}}}{\text{SMAC}}\right)_{\text{MIN. MOM.}}$</td>
<td>$\frac{1}{1+K}\left(\frac{H_{\text{max}}}{\text{SMAC}}\right)_{\text{MIN. MOM.}}$</td>
</tr>
<tr>
<td>FLAPPED</td>
<td>$\frac{1}{2}K\left[\left(\frac{\gamma_{\text{min}}}{2}\right)\gamma_{\text{max}}\right]$</td>
<td>$0$</td>
</tr>
<tr>
<td>FLAPPED</td>
<td>$\frac{1}{2}K\left[\left(\frac{\gamma_{\text{min}}}{2}\right)\gamma_{\text{max}}\right]$</td>
<td>$0$</td>
</tr>
<tr>
<td>TIMUM MOMENT CASE</td>
<td>$\frac{d^2H}{dC^2}$ $dC=0=0$</td>
<td>$\frac{d^2H}{dC^2}$ $dC=0=0$</td>
</tr>
</tbody>
</table>

**Table VII:** Maximum Hinge Moment, $\frac{H_{\text{max}}}{\text{SMAC}}$, for Hinge Locations of Table V.
<table>
<thead>
<tr>
<th></th>
<th>Minimum Positive Moment</th>
<th>Minimum Moment</th>
<th>Minimum Negative Moment</th>
</tr>
</thead>
<tbody>
<tr>
<td>LAPPED</td>
<td>810</td>
<td>273.5</td>
<td>413</td>
</tr>
<tr>
<td></td>
<td>(+96%)</td>
<td>(-33.9%)</td>
<td>(0)</td>
</tr>
<tr>
<td>OPTIMUM</td>
<td>849</td>
<td>286.6</td>
<td>433</td>
</tr>
<tr>
<td>AVIGATION</td>
<td>(+105%)</td>
<td>(-35.6%)</td>
<td>(+4.7%)</td>
</tr>
<tr>
<td>OPTIMUM</td>
<td>494</td>
<td>167.5</td>
<td>253</td>
</tr>
<tr>
<td>MOMENT</td>
<td>(+20%)</td>
<td>(-59.6%)</td>
<td>(-38.7%)</td>
</tr>
</tbody>
</table>

NOTE: \( \Delta W = 1/4 \), \( \Delta (W/L) = 143.5 - 122.0 \), \( \kappa = 0.325 \)
BASIC THICKNESS

VELOCITY DISTRIBUTION, $\frac{V}{V}$

1G-SERIES SECTION

CHORD STATIONS NOTED
ADDITIONAL VELOCITY DISTRIBUTION $\frac{\Delta V}{V}$

16-SERIES SECTION

CHORD STATIONS NOTED
CAVITATION SPEED VS. DEPTH

SALT WATER

\[ P_a - P_v = 2044 \text{ psf} \]
FLAP BASIC LOAD DISTRIBUTION

6 LESS THAN 20°

FROM TABLE III OF REF. 5.
CAVITATION BUCKET

EFFECT OF BUOYANCY AND DEPTH

AG(EN) FWD FOIL MODEL
INCIDENCE LIFT
ZERO PITCH

(\frac{W}{B}) DEPTH

--- 0 8.5 ft. REFERENCE BUCKET FOR INTERIM PFP.
--- 50 psf 6.5 ft.
--- 50 psf 9.33 ft. (1 MAC)

NOTE: BUOYANCY COMPARISON ACTUALLY EXISTS BETWEEN MODEL AND PROTOTYPE.
2. ALL FOLLOWING CURVES INCLUDE BUOYANCY.
CAVITATION BUCKET

EFFECT OF PITCH AND CAMBER

AG(EH) FWD FOIL
INCIDENCE LIFT
\[(W/S)_B = 90 \text{ psf}\]
9.33 ft. depth (1 MAC)

<table>
<thead>
<tr>
<th>PITCH</th>
<th>SECTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>16-(353)OB {MODEL}</td>
</tr>
<tr>
<td>1°</td>
<td>16-(353)OB {PROTOTYPE}</td>
</tr>
<tr>
<td>1°</td>
<td>16-(390)OB {REFERENCE BUCKET FOR THIS NOTE}</td>
</tr>
</tbody>
</table>

---

SPEED - KNOTS

0 200 400 600 800 1000 1200 1400 1600 1800 2000

FOIL LOADING, W/S ~ 0.054
OPTIMUM UPPER SURFACE CAVITATION BOUNDARIES

EFFECT OF OPERATING CONDITIONS AND S

<table>
<thead>
<tr>
<th>SECTION</th>
<th>S (ft)</th>
<th>PITCH deg.</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.545</td>
<td>8.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.280</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.193</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>0.146</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AG(EH) FWD. FOIL INCIDENCE LIFT CONTROL
90\% FLAP CHORD RATIO
NOTE: CURVE 4 is INTERIM REPORT REFERENCE.

EXISTING (UNFLAPPED) CAVITATION BUCKET

FOIL LOADING, W/S ~ PST

HAW 4/29/73
OPTIMUM FLAP SCHEDULES

EFFECT OF OPERATING CONDITIONS AND $\alpha$

<table>
<thead>
<tr>
<th>SECTION</th>
<th>$\delta$</th>
<th>DEPTH</th>
<th>PITCH</th>
<th>($C_l$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16.5</td>
<td>.545</td>
<td>8.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>.550</td>
<td>9.2</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>16.5</td>
<td>.550</td>
<td>9.2</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>.460</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AG CH FWD. FOIL INCLINATION LIFT CONTROL
20% FLAP CHORD RATIO

NOTE: CURVE #1 IS INTERIM REPORT REFERENCE.
INCIDENCE ANGLE AT OPTIMUM CAVITATION BOUNDARY

EFFECT OF OPERATING CONDITIONS AND $\alpha$

<table>
<thead>
<tr>
<th>SECTION</th>
<th>$\delta$</th>
<th>DEPTH</th>
<th>PITCH</th>
<th>$(\alpha/\delta)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16-(353)03</td>
<td>1.595</td>
<td>8.5</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>16-(350)03</td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>16-(350)03</td>
<td>9.33</td>
<td>1</td>
<td>90</td>
</tr>
<tr>
<td>4</td>
<td>16-(350)03</td>
<td>466</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AC(EM) FWD. FOIL
INCIDENCE LIFT CONTROL
20% FLAP CHORD RATIO

NOTE: CURVE 1 IS INTERNAL REPORT REFERENCE.
OPTIMUM UPPER SURFACE CAVITATION BOUNDARIES

EFFECT OF CAMBER AND FLAP CHORD

AG(II) Prototype FWD Foil
Incidence Lift Control
3' as in Table III
1° Pitch
(W/S) = 90 9.33 ft. depth

Note: Curve #1 is reference curve for this report.

EXISTING (UNFLAPPED)
CAVITATION BUCKET

| SECTION | FLAP
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16-(390)05  20</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>16-008      20</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
</tr>
</tbody>
</table>

SPEED-KNOTS

0 20 40 60 80 100 1200 1400 1600 1800 2000

FOIL LOADING, W/S - PS

HRW 9/24/73

GAC 335 REV. 4
9-71 EDM

GRUMMAN
AMERICAN ARGUS CORPORATION

REPORT
DATE
OPTIMUM FLAP SCHEDULES

EFFECT OF CAMBER AND FLAP CHORD

<table>
<thead>
<tr>
<th>SECTION</th>
<th>FLAP CHORD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>50</td>
</tr>
</tbody>
</table>

AG(EN) PROTOTYPE FWD. FOIL INCIDENCE LIFT CONTROL S AS IN TABLE IV
1st PITCH (W/S) = 20
9.33 FT. DEPTH
NOTE: CURVE #1 IS REFERENCE FOR THIS REPORT.
INCIDENCE ANGLE AT OPTIMUM CAVITATION BOUNDARY

EFFECT OF CAMBER AND FLAP CHORD

<table>
<thead>
<tr>
<th>SECTION</th>
<th>FLAP CHORD %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16-(330)08</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>16-008</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

AG(EH) PROTOTYPE FWD. FOIL INCIDENCE LIFT CONTROL 3 AS IN TABLE IV.
1º PITCH (W/S)B = 90
9.33 ft. DEPTH
NOTE: CURVE #1 IS REFERENCE FOR THIS REPORT.

INCIDENCE ANGLE, \( \phi \), - deg.

SPEED - KNOTS

REPORT DATE
4/23/73
REFERENCE FLAP SCHEDULES

AG(EH) PROTOTYPE FWD. FOIL
INCIDENCE LIFT CONTROL
20\% CHORD FLAP

OPTIMUM MOMENT

OPTIMUM CAVITATION

UNFLAPPED FOIL

30\% FLAP

REDDONNANCY

FLAP FOIL LOADING, \(L_s^0\) = \(C_s \cdot \frac{g}{g^0} - \rho^0 \cdot \frac{v^3}{2}\)

DYNAMIC PRESSURE, \(\frac{v^2}{2}\) ~ \(\text{psf/10}^3\)

FIG. 13

H\&W 4/20/73
CAVITATION BUCKET CONSTRUCTION

UNFLAPPED FOIL

AG(66) PROTOTYPE FWD. FOIL
INCIDENCE LIFT CONTROL
9.33 ft. (IMAC) DEPTH
10° PITCH
$(W/S)_B = 90 \text{ psf}$

NOTE: CHORD STATIONS INDICATED IN % AND ARE UPPER SURFACE UNLESS PREFIXED L.

---

SPEED  ~ KNOTS

0  200  400  600  800  1000  1200  1400  1600  1800  2000

FOIL LOADING, W/S ~ PSF

MIN. W/S  1.25  2.5  5  DES. W/S  MAX. W/S 4/24/73
CAVITATION BUCKET CONSTRUCTION

OPTIMUM CAVITATION FLAP SCHEDULE

AC(EH) PROTOTYPE FINE FOIL
INCIDENCE LIFT CONTROL
9.33 ft. (1 MVIC) DEPTH
1° PITCH
(W/S)ₚ = 90 PSF
20% CHORD FLAPS

NOTE: CHORD STATIONS INDICATED IN % AND ARE UPPER SURFACE UNLESS PREFIXED L.
CAVITATION BUCKET CONSTRUCTION

OPTIMUM MOMENT FLAP SCHEDULE

AC-CH Prototype FWD. FOIL
INCIDENCE LIFT CONTROL
9.33 ft. (1 MAC) DEPTH
1° PITCH
(W/S)_P = 90 PSF
20% CHORD FLAP'S

NOTE: CHORD STATIONS INDICATED IN % AND ARE UPPER SURFACE UNLESS PREFIXED L.

SPEED - KNOTS

0 20 40 60 80 100 120 140 160 180 200

FOIL LOADING, W/S ~ PSF

MIN. (W/S)  DES. (W/S)  MAX. (W/S)

1.25  2.5  5

GRUMMAN

GAC 535 REV. 4
4-71  28M

REPORT
DATE
CODE 26612
REFERENCE CAVITATION BUCKETS

AG(EH) PROTOTYPE FWD FOIL
INCIDENCE LIFT CONTROL
9.33 ft. (1 MAC) DEPTH
1° PITCH
(w/s) D = 90 psf
20% FLAP

--- UNFLAPPED

--- OPTIMUM CAVITATION FLAP SCHEDULE

--- OPTIMUM MOMENT FLAP SCHEDULE

FOIL LOADING, w/s ~ psf

MIN W/S

DES W/S

MAX W/S

0 200 400 600 800 1000 1200 1400 1600 1800 2000

SPEED - KNOTS

20 30 40 50 60 70 80
MINIMUM HINGE MOMENTS

AG(EH) FWD. FOILS

| FLAP SCHED | $H_c$ | $C_L$ | $M_{min}$/ 
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>UNFLAPPED</td>
<td>1.666</td>
<td>1.250</td>
<td>273.5</td>
</tr>
<tr>
<td>OPT. CAV.</td>
<td>0.633</td>
<td>1.082</td>
<td>236.6</td>
</tr>
<tr>
<td>OPT. MOD.</td>
<td>0.654</td>
<td>0.330</td>
<td>167.5</td>
</tr>
</tbody>
</table>

**Dynamic Pressure:** $q ~ \text{psf}/10^3$

**Graph:**
- Typ 1425 psi, $d/C = 1$
- Typ 1120 psi, $d/C = 1.1$
- Typ 1220 psi, $d/C = 1.2$

**Figure 18**

**Date:** 9/26/73
MINIMUM NEGATIVE HINGE MOMENTS

AG(EH) FWD. FOILS

<table>
<thead>
<tr>
<th>FLAP SCHED.</th>
<th>H/C</th>
<th>CL/C</th>
<th>H/CL</th>
<th>H/CLx10^6</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNFLATTED</td>
<td>0.415</td>
<td>4.13</td>
<td>10.4</td>
<td></td>
</tr>
<tr>
<td>OPT. COV.</td>
<td>0.524</td>
<td>4.33</td>
<td>10.9</td>
<td></td>
</tr>
<tr>
<td>&quot;OPT.&quot; MOM.</td>
<td>0.560</td>
<td>2.53</td>
<td>6.35</td>
<td></td>
</tr>
</tbody>
</table>

Dynamic Pressure, \( q \sim \text{psf/10}^3 \)

Typ,\( q_{14300\text{psf},1.25\%} \)
\( q_{14300\text{psf},1.0\%} \)
\( q_{12200\text{psf},0.75\%} \)

KNOTS:
30 KNOTS
50 KNOTS
MINIMUM POSITIVE HINGE MOMENTS

AG(EH) FWD. FOILS

<table>
<thead>
<tr>
<th>FLAP SCHEDULE</th>
<th>$H/C$</th>
<th>$C_{HL}$</th>
<th>$\frac{L_{max}}{S\cdot V_{AC}} \times 10^6$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNFLATTED</td>
<td>.86</td>
<td>.549</td>
<td>810 20.4</td>
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<tr>
<td>OPT. CON.</td>
<td>.92</td>
<td>.681</td>
<td>349 21.5</td>
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<tr>
<td>OPT. MDM.</td>
<td>.837</td>
<td>.532</td>
<td>406 12.5</td>
</tr>
</tbody>
</table>

Typical:

- $1435 \text{psf}$
- $1.25 \frac{\text{g}}{\text{d}^2 \text{E}}$

$1435 \text{psf}$
- $1.0 \frac{\text{g}}{d^2 \text{E}_\infty}$

$1200 \text{psf}$
- $0.75 \frac{\text{g}}{d^2 \text{E}_\infty}$

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DRUMMON ADAMS INCORPORATION

REPORT

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