MASON

AIAA 90-3262

MDO!

SELECTING WING & ENGINE SIZE

- ONE LEVEL MORE DETAILED EXAMINATION OF SIZING
- DIRECTLY EXAMINE the Roles of:
  1. ADVANCED TECHNOLOGY
  2. TECHNOLOGY INTEGRATION (MULTIDISCIPLINARY OPTIMIZATION)
- INSIGHT & METHODS to UNDERSTAND and INTERPRET the RESULTS of GIANT CODES

STATEMENT OF the PROBLEM

MINIMIZE WEIGHT,
Subject to range and point performance requirements.

i.e.

$$\text{minimize } W = W_{ENG} + W_{WNG} + W_{FUEL}$$

- EXAMINE COMPONENT TECHNOLOGIES

Approach:
- USE RESULTS OF Nicolai Sizing Program to provide nominal weight to start
- Think in terms of Wing Area as the independent variable.

WING WEIGHT EQN. : STRUCTURAL TECHNOLOGY

from Nicolai, for fighters

+ K_T = technology factor

$$W_{WNG} = 3.08 \cdot K_T \left(\frac{K_{piv} N \cdot W_{TO}}{t/c} \left\{ \left[\underbrace{\tan\Lambda_{LE} - \frac{2(1-\lambda)}{AR(1+\lambda)}}_{\tan\Lambda_{c/2}} \right]^2 + 1 \right\} \times 10^{-6} \right)^{.593} \underbrace{[(1+\lambda)AR]^{.89} S_W^{.741}}_{\text{regroup}}$$

K_{piv} - variable sweep factor = 1.175 (1 otherwise)

W_{TO} - TOGW

N - ultimate load factor, = 11. for fighters (7.33 × 1.5)

+ Standard Variables - t/c, Λ, λ, AR, S_W

$$W_{WNG} = 3.08\, K_T \left(\frac{N \cdot W_{TO}}{t/c} \left\{ 1 + \tan^2 \Lambda_{c/2} \right\} \times 10^{-6} \right)^{.593} (1+\lambda)^{.89} \cdot b^{1.78} \cdot S_W^{-.149}$$

!!

<u>DRIVERS</u>

Note

$\sim \frac{1}{(t/c)^{.6}}$

$\sim S_W^{.741}$ for fixed AR

$\sim S_W^{-.149}$!! for fixed <u>span</u>

$\sim (1+\lambda)^{.89}$

$\sim W_{TO}^{.6}$

Low Wing Weight $\Rightarrow$

- thick wings
- low span
- high taper (λ small)

PROPULSION

$$W_{ENG} = \frac{T_{ENG\ REQ'D.}}{(T/W)_{ENG}}$$

$\left(\frac{T}{W}\right)_{ENG}$ defines technology levels

> 12 HIGH TECH (VERY)

< 8 LOW TECH

AERODYNAMICS

$$C_D = C_{D_0} + \frac{C_L^2}{\pi AR E}$$

E - defines technology level

C_{D_0} - Configuration Integration, Discipline + some technology

$$E = E(C_L, M)$$

To Solve

$$W = W_{ENG} + W_{WNG} + W_{FUEL}$$

using S_W,

$$\frac{dW}{dS_W} = \frac{dW_{ENG}}{dS_W} + \frac{dW_{WNG}}{dS_W} + \frac{dW_{FUEL}}{dS_W} = 0$$

MANY VARIATIONS OF REQUIREMENTS
Possible starting with this statement.

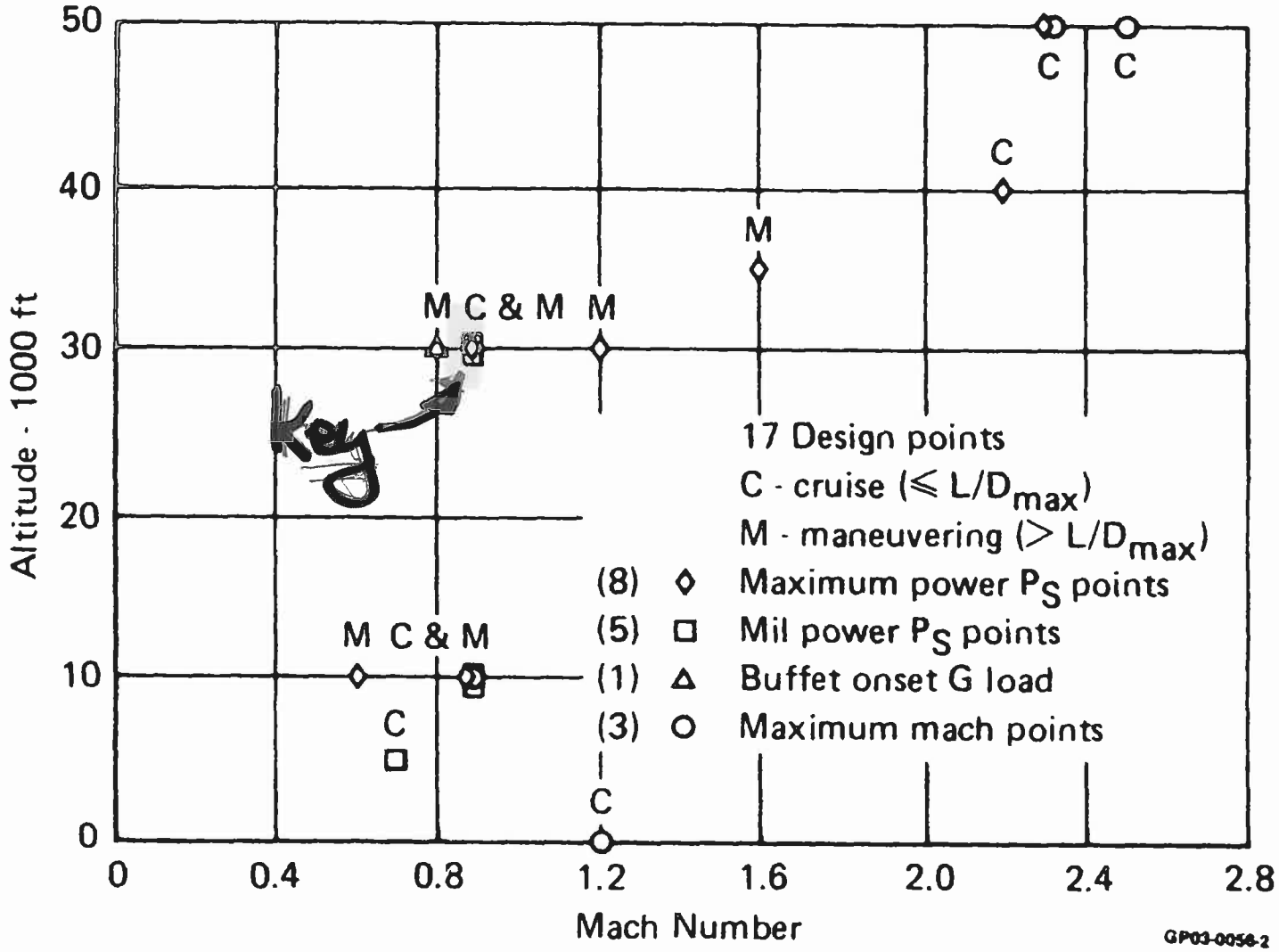
THE CLASSIC MANEUVER DOMINATED FIGHTER

- Assume the maneuver design point sizes the wing and engine.
- NEGLECT dW_{FUEL}/dS_W in ANALYSIS
- SPECIFY n_z at a given MACH, ALTITUDE,

  called Maneuver Design Point

  or <u>MDP</u>.

An Example: the F-15 - Design Points



From Larry Niedling, "The F-15 Wing Development Program", AIAA Paper 80-3044

RELATE THRUST to WEIGHT

$$W_{ENG} = \frac{T_{SLS\ MAX\ AB}}{(T/W)_{SLS\ MAX\ AB}}$$

$$\& \quad T_{SLS\ MAX\ AB} = \frac{T_{REQ'D}}{(T/T^*)(IF)}$$

$T_{REQ'D}$ = VALUE REQUIRED AT Specified MACH, ALTITUDE

T/T^* = RATIO AT ALTITUDE/MACH to installed at SL MAX AB

IF = Installation FACTOR (~.9)

$$W_{ENG} = \frac{T_R}{A}$$

$$A = (T/W)_{SLS\ MAX\ AB} \cdot (T/T^*) \cdot IF$$

$$W = W_{ENG} + W_{WNG}$$

$$W_{ENG} = T_R / A$$

$$\frac{dW}{dS_W} = 0 = \frac{dW_{ENG}}{dS_W} + \frac{dW_{WNG}}{dS_W}$$

$\frac{dW_{WNG}}{dS_W}$: take simple derivative of wing weight eqn.

$$\frac{dW_{ENG}}{dS_W} = \frac{1}{A} \frac{dT_R}{dS_W}$$

WHERE $T_R = D_{@MDP} = q S_W \left[C_{D_0} + \frac{C_L^2}{\pi A R E} \right]$

use given n_z: $\quad L = n_z W = q S_W C_L$

$$C_L = \frac{n_z W}{q S_W}$$

$$\& \quad T_R = q S_W \Big[\underbrace{C_{D_{0F}} \cdot \frac{S_F}{S_W} + 2 C_{f_e} F}_{C_{D_0}} + \frac{1}{\pi AR E} \cdot \frac{n_z^2 W^2}{q^2 S_W^2} \Big]$$

$$\frac{dT_R}{dS_W} = 2 C_{f_e} F q - \frac{1}{\pi AR E} \cdot \frac{n_z^2 W^2}{q} \left(\frac{1}{S_W^2} \right)$$

$$= C_{D_{0W}} q - q K C_L^2$$

where $K = \dfrac{1}{\pi AR E}$

$$\frac{dT_R}{dS_W} = q \left[C_{D_{0W}} - K C_L^2 \right]$$

Substituting into $dW/dS = 0$:

$$\frac{dW_e}{dS_W} + \frac{dW_{WNG}}{dS_W} = 0 = \frac{1}{A}\frac{dT_R}{dS_W} + \frac{dW_{WNG}}{dS_W}$$

$$= \frac{1}{A} q\left[C_{D_{OW}} - KC_L^2\right] + \frac{dW_{WNG}}{dS_W}$$

<u>OR</u>

$$0 = C_{D_{OW}} - KC_L^2 + \frac{A}{q}\cdot\frac{dW_{WNG}}{dS_W}$$

& solve for C_L:

$$\boxed{C_{L_{MDP}} = \sqrt{\frac{1}{K}\left(C_{D_{OW}} + \frac{dW_{WNG}/dS_W}{q\,(1/A)}\right)}}$$

$$\frac{1}{A} = \frac{1}{T/W)_{\substack{SLS\\MAX\\AB}}\cdot(T/T_*)\,IF} = \frac{\partial W_E}{\partial T_R}$$

$$C_{L_{MDP}} = \sqrt{\frac{1}{K}\left(C_{D_{OW}} + \frac{dW_{WNG}/dS_W}{q\, dW_{ENG}/dT_R}\right)}$$

WING C_{D_0}

- Aero
- Structures
- Propulsion

ORIGINALLY: Herring, McDonnell Aircraft (F-15)

$S_W = ?$

$$L = n_z W = q S_{OPT} C_{L_{MDP}}$$

$$S_{WNG_{OPT}} = \frac{n_z W}{q C_{L_{MDP}}}$$

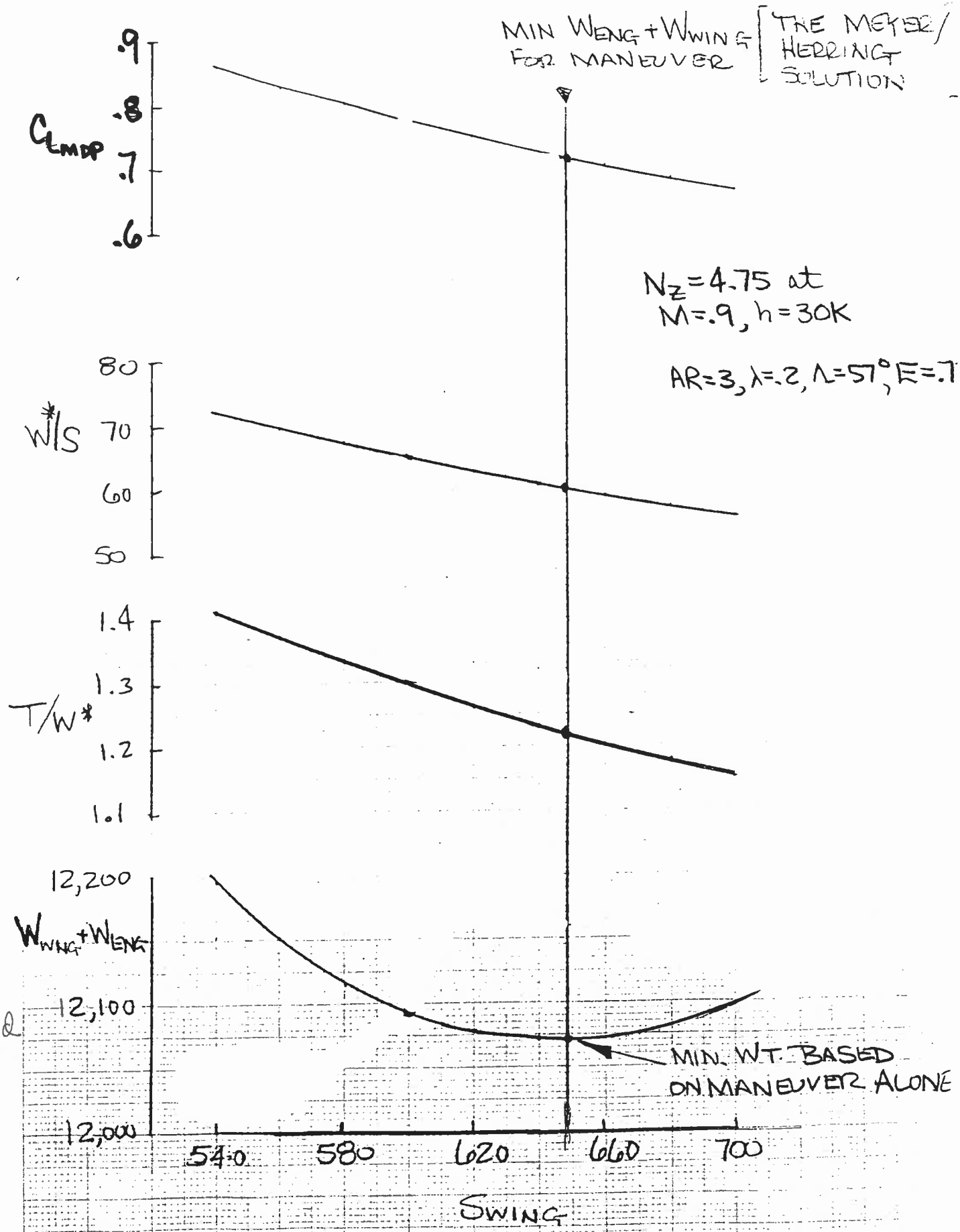


Figure 1. OPTIMUM WING SIZE : ENGINE SIZED EITHER FOR MANEUVER OR ACCEL.

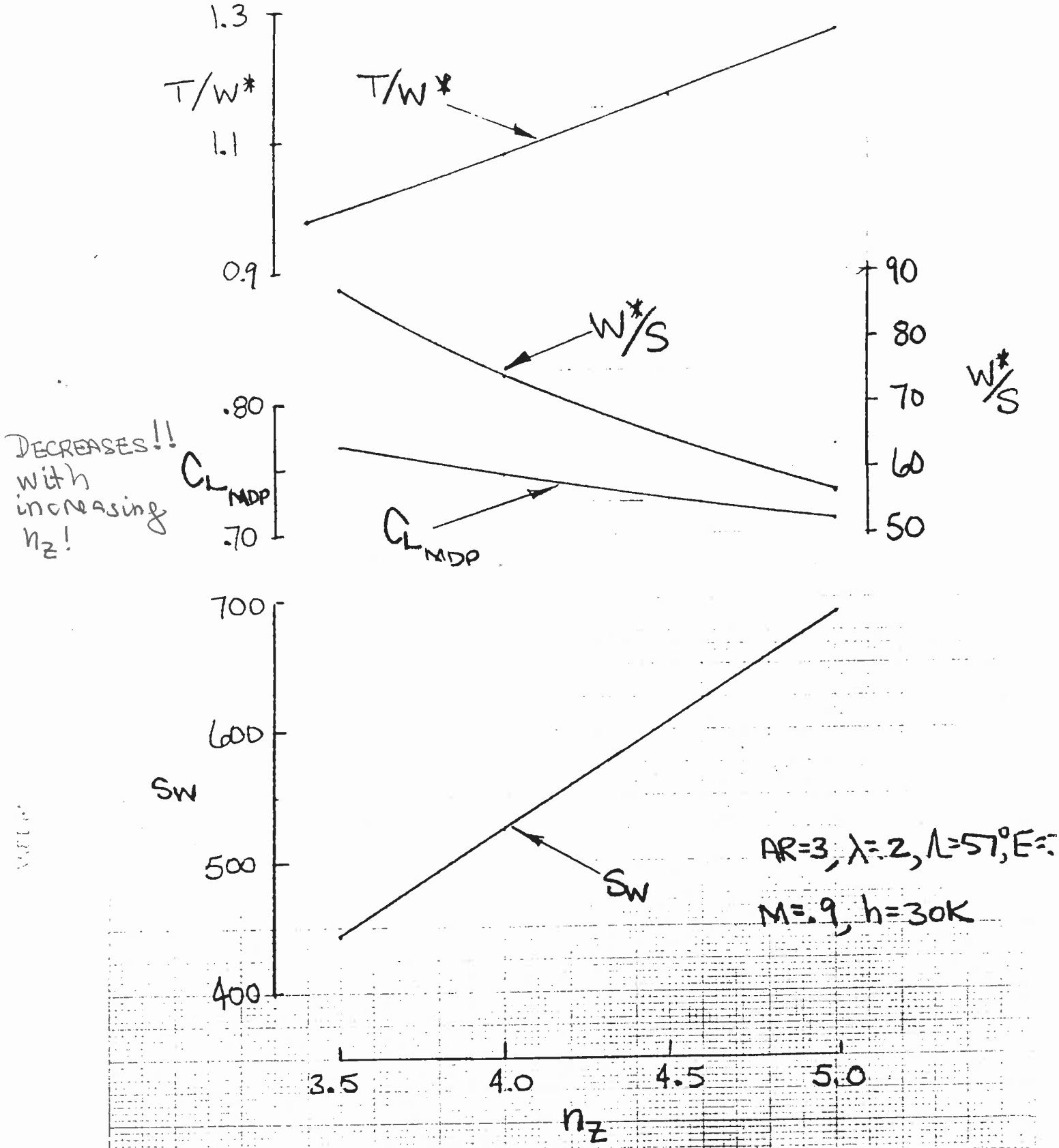


Fig. 2. EFFECT of MANEUVER REQ'T. ON WING SIZE & LIFT COEFFICIENT. - WING & ENGINE SIZED FOR MANEUVER.

1ST VARIATION ON CLASSIC MANEUVER PROBLEM

Question: WHAT HAPPENS IF ENGINE IS SIZED BY the ACCEL?

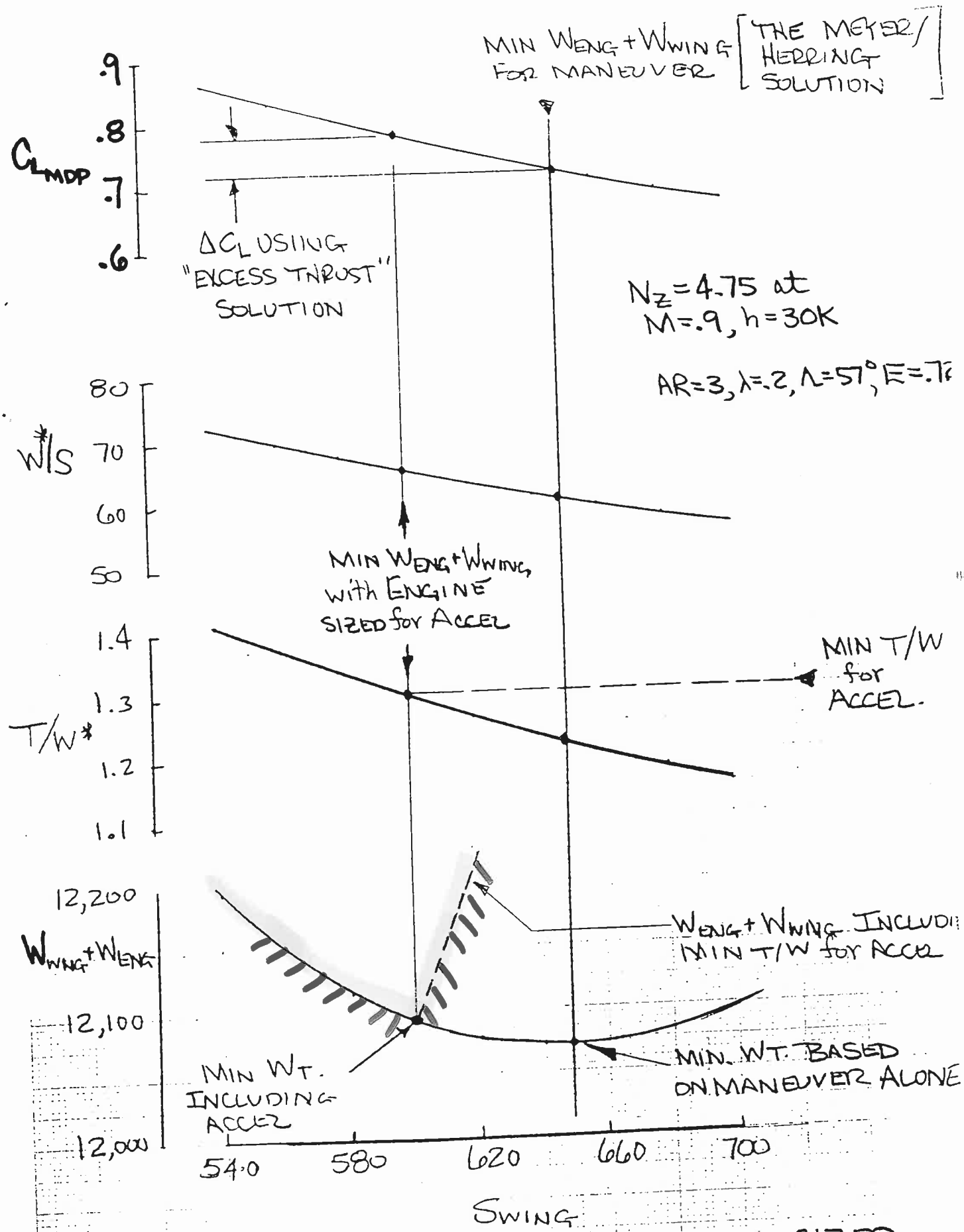


Figure 1. OPTIMUM WING SIZE : ENGINE SIZED EITHER FOR MANEUVER OR ACCEL.

CONCLUSION

- THERE IS A RATIONAL METHOD TO FIND WING AREAS and ENGINE SIZE

- YOU SHOULD ALWAYS BE ABLE TO CONSTRUCT "BACK OF the ENVELOPE" ANALYSIS ALONG The Lines given here to support ACSYNT type code sizing work.