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NAVAL AIRSHIP PROGRAM FOR SIZING AND PERFORMANCE

-NAPSAP-

Computer Program Development: Program Update No.2

Contract No. N62269-81-M-3248

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
This report describes a computer program which has been developed by Lancaster Analytics under U.S. Navy Contracts N-62269-78-M-4462, N-62269-79-M-2870, N-62269-80-M-2376, and N-62269-81-M-3248. This program, called NAPSAP, for Naval Airship Program for Sizing And Performance, performs preliminary vehicle design and performance evaluations for both rigid and

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non-rigid Lighter Than Air (LTA) vehicles. Program capabilities have been tailored to vehicle sizes and missions currently being investigated as a part of the joint U.S. Navy - U.S. Coast Guard Maritime Patrol Airship, MPAS, Program and U.S. Navy Operational Mission Applications.

The NAPSAP computer program has been developed to assist the LTA Project Office at the Naval Air Development Center (NADC) in exploring the technical and operational feasibility of modern LTA vehicles.

The program has been designed to operate on a minimum of input data (only five cards are necessary) but has the capability to examine the influence of some 40 key parameters. NAPSAP provides easy parametric analysis in any of several optional levels of detail. The level of technology can be adjusted, the propulsion type can be varied. Propellers or rotors can be analyzed on a Point Design basis. Sensitivities of key variables can be examined separately or in combination. An optimization capability on multiple independent variables is a soon-to-be added option.

Once the design section of NAPSAP converges on a vehicle which meets the input requirements (such as maximum speed, payload, endurance, etc.) this vehicle can then be operated against a specified mission profile. All key parameters are monitored by specified time increments.

This report documents several program developments which have been included in NAPSAP during the last year. These include the addition of more detailed static aerodynamic coefficients, configuration/geometry details, static weight and balance calculations and the capability to analyze mission performance in towing operations in considerable detail.

The program architecture of NAPSAP is organized for quick modification or expansion. In its present form core memory size is 150K octal words on CD 6600 or 600 K bytes on IBM equipment. Normal run time is less than 4.0 CPU seconds.

ACKNOWLEDGEMENTS

Lancaster Analytics wishes to acknowledge the excellent technical support provided by Messers David B. Bailey and Rich Adams of NADC.

Mr. Bailey provided guidance and direction to the overall program development effort and provided definitive program requirements for application to the Maritime Patrol Airship Study Program and Advanced U.S. Navy Mission Applications. Mr. Bailey also supplied LTA technical reference information, both historical and from recent study efforts, which were necessary for various elements of the program formulation. His efforts were ably supported by Mr. Rich Adams who performed a large amount of the total programming and debugging effort.

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1.0 INTRODUCTION

1.1 BACKGROUND

This report presents a supplement to NADC Report No. 79206-60 published in January 1980 and NADC Report No. 80075-60 published in September 1981 which describe the Naval Airship Program for Sizing And Performance, NAPSAP (Reference 1). The purpose of this supplement is to describe several additions and/or extensions to the basic program methodology which have been included into the NAPSAP program during 1982.

In order to allow the reader to use this report as a stand alone overview of the NAPSAP program's capabilities, Section 2 contains a summary of NAPSAP program applications and assumptions and a brief over view of the general program methodology.

The remaining sections of this report summarize results of the current contract effort:

Section 3.0 - Vehicle Aerodynamics
Section 4.0 - Car Geometry and Configuration Details
Section 5.0 - Vehicle Static Balance, Car and Engine Location Analysis
Section 6.0 - Steady State Towing Mission Profile Evaluation
Section 7.0 - Analysis of Negative Angle of Attack Effects and Automatic Reballasting
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Appendix A: Induced Drag Analysis
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2.0 PROGRAM APPLICATIONS AND ASSUMPTIONS

2.1 PROGRAM APPLICATIONS OVERVIEW

There are several major applications for the current NAPSAP program (see References 1 & 2 for a detailed discussion and Reference 3 for a brief program overview). The first allows a vehicle to be sized in terms of a simplified set of input data and its performance to be evaluated in terms of payload as a function of range at the input design speed. This application is referred to as the NAPSAP Basic Case. The second major application allows the performance of the Basic Case vehicle to be evaluated over multi-segment mission profiles. There are several options which may be exercised for parametric analyses and sensitivity studies of these two basic program applications.

NAPSAP currently can analyze two types of LTA vehicles: rigid airships of the conventional Zeppelin type construction (eg, wire braced main frames, longitudinal girders with cruciform empennage; see Reference 4); and non-rigid airships similar to the type most recently operated by the U.S. Navy. Either type of vehicle can be analyzed at a range of gross weights including those greater than the total static lift (ie, in a "heavy" or overload condition). Program methodologies for non-rigid airships are far more rigorous than for rigid vehicles due to the larger and more recent data base on which to base the program algorithms.

The propulsion system may be sized for either a conventional take off using a ground run to develop aerodynamic lift or for vertical take off at maximum gross weight. Three types of engine cycles may be utilized; gas turbines, diesels, or gasoline powered reciprocating engines. Rotors or propellers may be analyzed on a point design basis by utilizing subroutines described in Reference 1.

General program methodologies and assumptions are briefly described in the following subsections.

2.2 PROGRAM METHODOLOGY OVERVIEW

The basic NAPSAP program methodology is illustrated in the top level flow chart of Figure 2.1. Areas which have been modified under the current study effort are included.

2.2.1 BASIC SIZING PROGRAM

Input data is read in and program initializations are performed. Vehicle design and performance characteristics input are used to size the vehicle and determine its overall geometrical characteristics.

The vehicle's basic aerodynamic characteristics are calculated for zero angle of attack and the angle of attack required for cruise at maximum take-off gross weight. The drag at the input design conditions gross weight (WGROSS), design speed (VDES), and design altitudes (HDES) are used to determine the horsepower required for cruise.

If VTOL is required, the horsepower requirements for vertical take off at maximum take-off gross weight are also calculated.

The largest required horsepower (cruise or VTOL) sizes the propulsion. The number of engines (thrustors) is a key (but optional) input variable.

Next, the vehicle weight characteristics are calculated. These include the non-propulsive structure weight, the total propulsion system weight, the vehicle systems weights, the total vehicle empty weight, and the useful load.

For all run types, the vehicles' generalized performance is calculated in terms of payload as a function of range at the input design speed and altitude.

The program calculations may be terminated at this point or any of the program options may be exercised. These options include sensitivity studies via the KF(i) correction factor option(multiple runs are required to utilize this program capability), parametric studies via the change design variable option (RUNTYP = 1), evaluation of the vehicle's mission profile performance (RUNTYP = 2), or evaluation of the basic vehicle's generalized performance at cruise speeds below the design speed (RUNTYP = 3). The program calculation options are illustrated in Figure 2.2 and briefly described below.

2.3 RUN TYPE DESCRIPTION

The NAPSAP program has the capability of running four (4) different types of runs (RUNTYP = 0, 1, 2, 3) controlled by the control variable RUNTYP (see also Reference 1).

RUNTYP = 0

This option is referred to as the "basic case". This option sizes the vehicle described by the input data and evaluates the vehicles "generalized performance" capability; ie, the payload vs range capability of the vehicle flying at the design airspeed (VDES) at the design altitude (HDES) with no wind.

RUNTYP = 1

This option allows parametric studies to be made where one or more variables are changed from the "basic case" inputs. The variables which can be changed include; hull volume, gross weight, static lift to gross weight ratio (Beta), design speed, design altitude, number of engines and vehicle length to diameter ratio. A single card is input with the new value(s) of the variable(s) to be changed following the "basic case" inputs. Input variables are changed per this card and a "basic case" (RUNTYP = 0) program evaluation is rerun. Additional "change input" cards may be input following the first card to allow multiple or "stacked cases" to be run with only a single set of basic input data.

RUNTYP = 2

This RUNTYP is used to evaluate the performance capability of vehicles sized according to the basic inputs over a specified (input) mission profile. Mission profile input data is input following the "basic case" data. Vehicle resizing iterations over the input mission profile are controlled by a mission profile control variable, FOMVAR. If FOMVAR = 0, no iteration or vehicle resizing is performed. Vehicle performance capability for the specified profile will be estimated based on the results of the single MISPFL subroutine evaluation.

If FOMTYP = 1 is input, the vehicle volume will be changed and the vehicle will be resized and re-evaluated over the input mission profile. MITER (maximum = 20) iterations will be performed in an attempt to converge on the "exact" vehicle volume required to satisfy the input mission profile. All other basic inputs will remain the same.

If FOMTYP = 2 is input, the input Beta will be changed and the vehicle will be resized and re-evaluated over the input mission profile. MITER iterations will be performed, each time changing Beta by an amount equal to PCTVAR * BETA (where PCTVAR is an input control variable for RUNTYP = 2 runs). If not input, a value of 0.05 will be used for PCTVAR. No "convergence" attempt is performed with the BETA iteration as is done with the volume iteration. The iterations are performed with a SIGN on the PCTVAR which reduces the total expendables weight (fuel + auxiliary power fuel + expendables weights) required to fly the vehicle over the input mission profile.

The capability to utilize a multi-variable optimization routine is under consideration at NADC and will be documented in a future report if this capability is completed.

RUNTYP = 3

This run option allows a vehicle sized for the basic inputs to be evaluated in terms of the "generalized performance" at (still air) airspeeds less than or equal to VDES. With RUNTYP = 3 input on the input control card, the program will then read NVFM values (maximum = 8) of other velocities, XV(i), at which the vehicles range versus payload performance will be evaluated. No other inputs are changed and the vehicle is not resized. Performance is evaluated in terms of payload versus range at each value of XV(i).

A brief discussion of key assumptions and analysis methods utilized in the basic program are discussed below. Details may be obtained from References 1, 2, & 3.

2.4 GENERAL ASSUMPTIONS

This section describes the assumptions utilized in the NAPSAP program as described in Reference 1. Extensions to these methodologies are described in Reference 2 and in the remaining sections of this report.

In general, the program assumes "off the shelf" state of the art in all vehicle design and performance areas. Estimated vehicle design and weight characteristics are based on historical U.S. Navy airship "actuals" supplimented by the more recent NASA and Navy LTA related study results.

Aerodynamics

Total vehicle drag coefficient at zero angle of attack is estimated on a simplified component build up approach based on drag breakdown of prior U.S. Navy non-rigid airships (see Reference 1 and Bibliography). No drag improvements due to vehicle clean-up or stern propulsion system are assumed. Both of these areas could produce significant drag reductions and should be more carefully evaluated in future programs. Drag due to lift or induced drag is based on the expression used throughout the previous U.S. Navy airship programs, simply $C_{Di} = 0.9 * C_L^2$.

Results of a re-examination of this assumption conducted during the current contract and discussed in Appendix A indicate that, contrary to previous assumptions, this may be a VERY OPTIMISTIC assumption. Lift coefficent as a function of angle of attack for all non-rigid vehicles is approximated by that of the ZPG-3W as used in the ANVCE ZPG-X Study (Reference 5). Additional vehicle aerodynamic coefficients required for steady state towing performance evaluations have been developed under the current contract. These are described in Section 3.0.

Propulsion

All propulsion calculations are based on "rubberized" engines using either gas turbines, diesels, or gasoline powered reciprocating engines and conventional propellers which are tilted for vertical take off, landing, hover, and towing operations. Horsepower requirements are based on the largest horsepower required for vertical take off at maximum take off gross weight or dash at maximum take off gross weight at the input (design) speed and altitude. Propellers are sized by an approximation of Hamilton Standard propeller performance estimating algorithms.

Separate subroutines have been developed for detailed point design analyses of either rotors or propellers (Reference 1).

Fuel consumption for each engine cycle is corrected for airspeed, altitude, and, most importantly, throttle effects, not only for the basic case, but throughout the mission profile evaluations and all other vehicle performance analysis options.

Weights

Propulsion system weights are based on the algorithms of Reference 6. The envelope weight is one of the most important weight components of non-rigid vehicles. This weight group has been analyzed in detail as described in Reference 2.

The car and fin weight estimating relationships are also based on previous U.S. Navy airships and References 5 & 7. In future program development efforts, more detailed WERs should be developed for the car and fin weight groups which reflect more advanced technology approaches and corresponding weight improvements.

Rigid airship structural weight is estimated from data utilized in the NASA Ames version of the Boeing Cascomp computer program (Reference 8). Advanced state of the art materials effects may be applied to the rigid WERs based on the results presented in Reference 6. A top level rigid group weight option is described in Reference 2.

Overall, the total vehicle empty weight estimated by the NAPSAP program should be conservative and achievable with "off-the-shelf" technology and design approaches available as of 1980.

A program option allows specific vehicle characteristics (aerodynamics, propulsion and weights) to be modeled.

The remaining section of this report describe extensions and enhancements of the NAPSAP program methodologies developed under the subject contract.

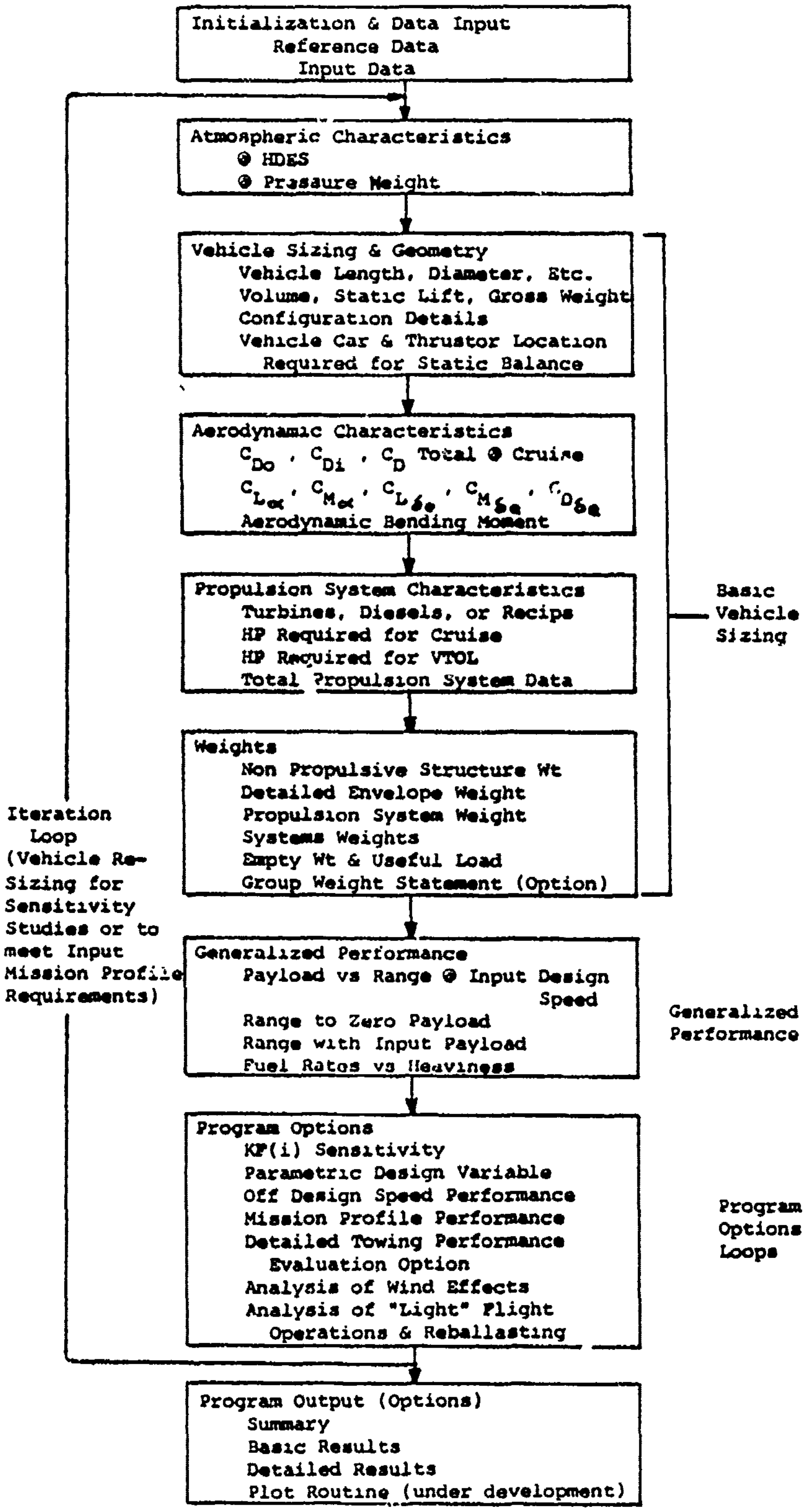


FIGURE 2.1: BASIC PROGRAM METHODOLOGY OVERVIEW

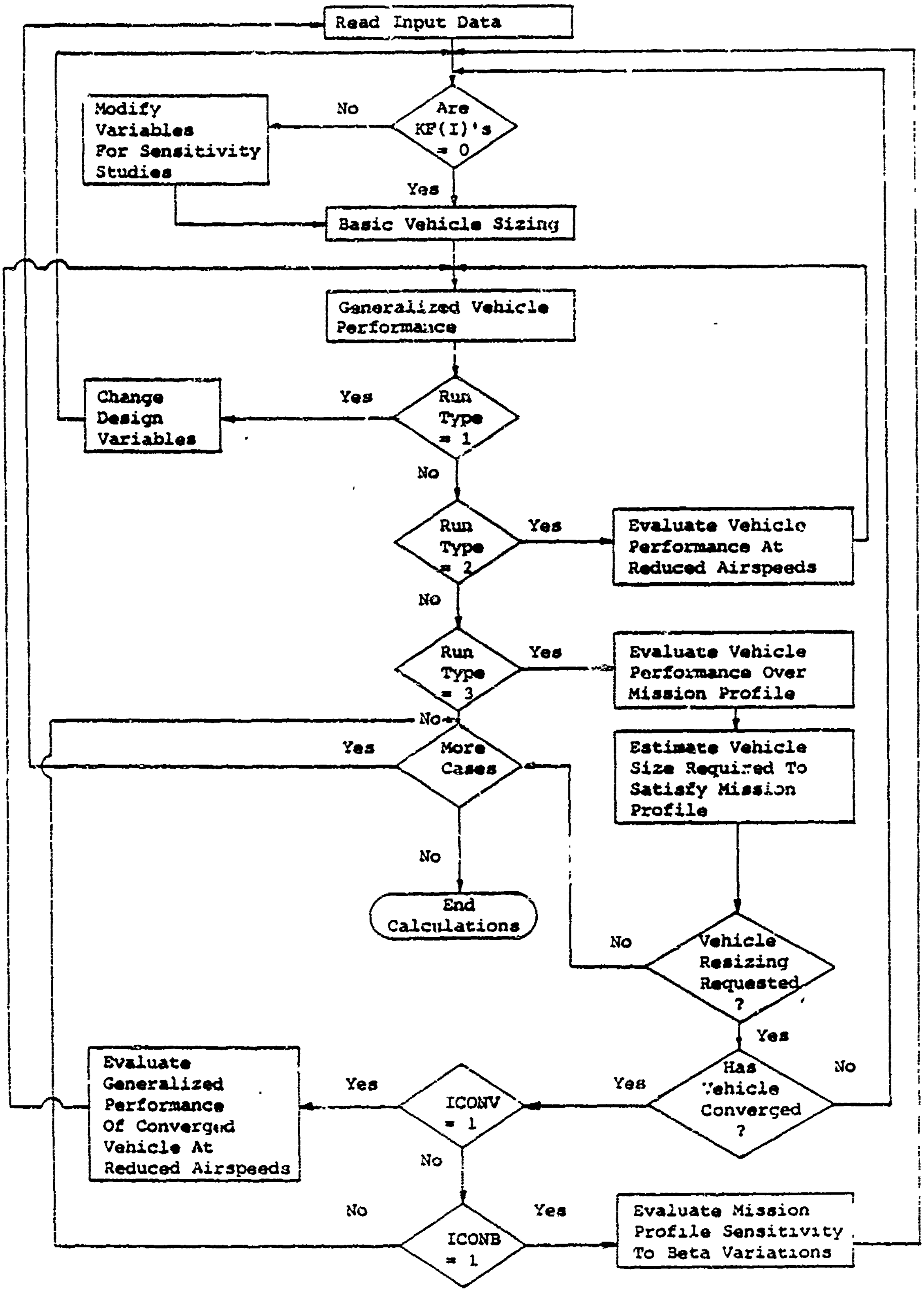


FIGURE 2.2: NAPSAP PROGRAM CALCULATION OPTIONS

3.0 VEHICLE AERODYNAMICS

The basic NAPSAP program calculates zero angle of attack drag and total drag, zero lift drag plus drag due to lift as described in References 1 & 2. The basic equations utilized are:

$$C_{D_{Total}} = C_{Do} + KC_L^2$$

where C_L is the lift coefficient required at the maximum take off gross weight and design airspeed and altitude. The basic value of "K" has been 0.9 unless modified by a KF(i) sensitivity option variable. One of the conclusions of the current contract effort (see Appendix A) is that the value of 0.9 may be optimistic.

The primary objective of the aerodynamics analyses of the current contract was to develop estimating algorithms for all of the aerodynamic coefficients required to evaluate vehicle performance in STEADY STATE towing operations.

The aerodynamic data analysis effort was based on Navy Contractor Performance Reports, recent Navy study reports, and the author's own personal notes. Key data sources included:

Vehicle/Volume (Ft^3)	GER No. & Date	Navy Contract No. Of Ref. Report
ZP4K - 1/527,000	5269 (1953)	NOa(s)-51-366
XZP5K /650,000	5268 (1953)	Noa(s)-55-185 et al
ZPG - 2W/975,000	5589 (1954)	Noa(s)-52-984 et al
ZPG - 3W/1,500,000	5915 (1955)	NOa(s)-54-900
ZPG - X /1,500,000	16456 (1977)	N62269-76-M-4325

Solution of the steady state towing equations of motion, requires the following aerodynamic derivatives. These derivatives were analyzed for the above family of vehicles.

$C_{L\alpha}$ @ $\alpha = 0$

$\frac{dC_L}{d\delta_e}$ @ $\alpha = 10^\circ$

$C_{M\alpha}$ @ $\alpha = 0$

$\frac{dC_M}{d\delta_e}$ @ $\alpha = 0$, & 10°

$\frac{dC_D}{d\delta_e}$ value derived at $\alpha = 6^\circ$ linearized at $\delta_e = 20^\circ$

$\frac{dC_D}{dC_L^2}$ evaluated at $\delta_e = 0^\circ$

In addition, the elevator deflection angle required to trim the vehicle in steady state, static flight was also derived as a function of angle of attack.

The reference data base of aerodynamics data are summarized below for four fin vehicles:

$C_{L\alpha}$ = .0125 / deg (see also Table 3.1)

$\frac{dC_L}{d\delta_e}$ = .0045 / deg

$$C_{M_\alpha} = .013 \ / \ deg$$

$$\frac{dC_M}{d\delta_e} = .0052 \ / \ deg$$

$$\frac{dC_D}{d\delta_e} = .00121 \ / \ deg$$

In the near future, table values for the three fin reference vehicle may be used in three fin configurations. However, the above four fin values could be utilized with only minor error.

The static trim combination of alpha and delta (angle of attack and elevator deflection angle) for the four reference vehicles is approximated as

$$\delta_{e_{Trim}} = 2 * \alpha$$

A comparison of the NAPSAP lift coefficient as a function of angle of attack is presented in Table 3.2.

The above coefficients provide all aerodynamic data required for evaluation of steady state tow performance.

TABLE 3.1:

Reference Vehicle Aerodynamics Data

Vehicle	$C_{L\alpha}$	$C_{M\alpha}$	$C_{L\delta e}$	$C_{M\delta e}$	$C_{D\delta e}$ ***
3W **	.013	.013	-.004	.005	.001
2W **	.0125	.0125	-.005	.0055	.00145
ZP4K *	.0115	+.0143	-.00374	.00499	.001175
ZP4K *			-.003025		
XZS2G * (3 fin)	.0129	.0125	-.00485	.00584	.00085 **

* Tables only, no curves

** Lancaster Analytic's calculation from plotted data

*** Evaluated at $\alpha = 6^\circ$ & linearized over $\delta e = 20^\circ$

TABLE 3.2: C_L vs α

α	Basic NAPSAP	ZPG-X	3W (GER 6915)	2W (GER 5589)
4°	.0515	.0498	.055	.055
8°	.114	.115	.112	.112
10°	.153	.151	.14	.145
12°	.196	.192	.175	.184

4.0 CONFIGURATION DETAILS/CAR GEOMETRY DEFINITION

Previous to the current contract effort, car length was not a critical design variable in any NAPSAP evaluation methodology. Car length had been simply estimated as 25% of the total vehicle length and had no impact on any vehicle performance evaluations.

Due to the added detail required for proper analysis of the vehicles static (weight) balance and steady state towing operations, a more accurate car length estimation algorithm was needed. Car length defines the actual (required) location of the engines in order to achieve a statically balanced vehicle weight distribution.

The approach utilized in formulating the car length algorithm was to analyze prior vehicle characteristics in order to find some correlation parameter(s).

Table 4.1 presents data for car length characteristics of various vehicles. The data includes total vehicle length, (L_{veh}), volume, $(volume)^{1/3}$, vehicle length/ $V^{1/3}$, car length, car length/$(volume)^{1/3}$, car length/vehicle length and a comparison of the car length as predicted by the new NAPSAP car estimating algorithm and the prior vehicle actuals.

Pertinent observations and conclusions made from the analysis include:

1) Use of a 25% of total vehicle length for car length is not sufficiently accurate for NAPSAP detailed analyses purposes.

2) Car length of previous Naval airships does not correlate well with total vehicle length alone.

3) Car length normalized by $(\text{volume})^{1/3}$ correlates fairly well with $(\text{volume})^{1/3}$ in between certain limits.

The NAPSAP car length estimating algorithm is:

$$\text{CARLTH} = \left[-.8 + 0.0174\,(\mathcal{V}^{1/3})\right]\ \mathcal{V}^{1/3}$$

subject to upper and lower limits of

$$\text{if } \mathcal{V}^{1/3} \leq 55,\ \text{CARLTH} = 0.45\,\mathcal{V}^{1/3}$$

$$\text{if } \mathcal{V}^{1/3} > 95,\ \text{CARLTH} = 0.88\,\mathcal{V}^{1/3}$$

The car lengths predicted by the above equation are calculated in Table 4.1 for comparison with the actual car lengths. The results predicted by the NAPSAP algorithm are acceptably close to the actual vehicle data base.

Car Height

Table 4.2 presents the volumes, average car height to the theoretical envelope contour, and car length for the same data base of vehicles. From this data it was concluded that car height is essentially independent of vehicle volume, car length, or, essentially any other parameter. This follows logically since the interior is dictated by normal operation of standing personnel. Except for the Goodyear GZ 20, a car height of 14 feet would within 11% for all of the above vehicles. This value is used in NAPSAP for dimension No. 18 in the Reference 2 configuration details.

TABLE 4.1

Calculation of New Car Length Estimating Algorithm

Vehicle Length Lveh	Volume V	$V^{1/3}$	Lveh/ $V^{1/3}$	Actual Car Length	NAPSAP Car Estimating Equation 7/82	Lcar/$V^{1/3}$ (**)	Lcar/ Lveh (**)
249	456000	76.6	3.25	42.5	40.8	.555	.1706
321	875000	95.2	3.37	83	83.8	.87	.258
282	650000	86.2	3.27	59	60.32	.684	.209
339	975000	98.7	3.43	83	86.4	.84	.245
263	527000	80.4	3.27	43.5	48.15	.54	.165
404	1516000	[illegible]	3.53	83	100.6	.726	.205
192	202000	58.4	3.28	23	28.3	.39	.12
160	147000	52.6	3.04	23	23.7	.44	.14
500	$3 * 10^6$ (*)	143.5		126.3			

(*) Estimated 3MCF Vehicle Characteristics

(**)Note the lack of correlation.

TABLE 4.2

Car Heights, Lengths and Volumes

Name	V	Avg. Car Height	Car Length
ZP2K[1]	456000	14.0	42.5
ZPM-1[1]	625000	13.5	117.4
ZPN-1[1]	875000	12.3	83.0
XZP5K[1]	650000	12.5	59.0
ZPG-2[2]	975000	14.2	83.0
ZSG-4[2]	527000	14.2	43.5
ZPG-3W[2]	1516300	14.2[3]	83.0
GZ 20[4]	202000	8'	23.0

Notes:

(1) GER 5196

(2) Calculated/measured by JWL from vehicle weight and/or performance reports.

(3) Same car (exterior dimension wise) as designed and used on ZPN-1 and ZPG-2W.

(4) Goodyear Aerial Surveillance Platform brochure - probably does not belong in the data set since mission/ design criteria are based on advertising operations.

Note that the above car height is valid even for "double deck" interiors such as used on the 2W and 3W vehicles.

Additional car related configuration dimensions are discussed in the following section.

5.0 VEHICLE STATIC BALANCE ANALYSIS

The objective of this task effort was to develop the program logic necessary to analyze the vehicle static weight and balance and thus define the overall vehicle configuration details, engine (thrustor) location (and, therefore, the effective thrust moment arms), and the vehicle center of gravity location.

The first step is to analyze the vehicles horizontal mass distribution in order to define the car location necessary to place the vehicle center of gravity (CG) directly below the vehicle center of buoyancy (CB). The approach utilized was to examine the major weight groups and subgroups estimated in the basic NAPSAP methodologies (Reference 1) and define those which should be considered in the static balance calculations.

The NAPSAP weight groups selected were the following:

NAPSAP Variable	Description
BAGWT	- the basic envelope weight
WBS	- the bow stiffening group weight
WBA	- the ballonet and airlines weight
WSS	- the suspension system weight
WEMISC	- the miscellaneous envelope weight
WENGT	- the total propulsion group weight
WENGPE	- the propulsion weight per engine

NAPSAP Variable	Description
WPRESS	- the pressurization system group weight
WCAR	- the car group weight
WFINS	- the fin group weight
WLNDGR	- the landing gear group weight
WSYSTS	- the systems group weight
UL	- the useful load

In order to solve the static weight and balance equations several assumptions and data inputs were required:

Assumptions and Notes:

1) Note that the sum of all of the above weights is equal to the total vehicle gross weight.
2) The useful load, car weight, and systems weight are assumed to be uniformly distributed over the total length of the car.
3) Effective moment arms for the above weight groups were estimated from prior vehicles.
4) In the horizontal plane the moment reference point is on the vehicle centerline axis at the theoretical envelope nose. (This is the same as that used on prior Naval Airship weight and balance reports.)
5) In the vertical plane, the envelope centerline axis is the moment reference point. This too is in accordance with prior analysis except that for the car and any weight groups included in the car group were referenced to the car water line. For the NAPSAP analysis and data reduction, vertical moment calculations are referenced to the envelope centerline.

6) The total propulsion system weight , including outriggers, is assumed to be equally divided between all engines.

Horizontal Plane Equations

For the horizontal plane analysis, the objective is to position the car such that the total vehicle CG is at the same longitudinal position as the CB. Thus, the required equation:

$$CG = \frac{\sum \text{moments}}{\sum \text{weights}} = CB$$

This equation is expanded to:

$$CG = CB = \frac{\sum_i \text{weight group(i) * moment arm(i)}}{\sum_i \text{weight group(i)}}$$

The CB is known from the geometry subroutine (see Reference 2). The equations can be expanded and simplified such that the only unknown is the location of the forward point of the car, XCARF. This point is point "4" in Figure 5.1. In order to reduce the equations to only one unknown (XCARF), an assumption is required on the location of the engine(s) and their associated moment arm. These are discussed below for each configuration.

Horizontal Plane Moment Arms

Moment arms have been derived from weight and balance reports on the ZS2G-1, ZP4K (ZSG4), and the PG-2 vehicles. The averaged values, normalized with respect to total vehicle length are:

XBAG = 0.4705
XBS = 0.0303
XSS = 0.4397
XBA = 0.4623
XEMISC = 0.6167
XFINS = 0.87605
XLNDGR = assumed equal to CB
XCAR = 0.5 of total car length + XCARF
XUL = 0.5 of the total car length + XCARF
XSYSTEMS = 0.5 of the total car length + XCARF
XENG = see specific discussion for each configuration

Two Engine Configuration

For a two engine configuration, the effective CG of the engines (and the longitudinal position of the thrust vector) are assumed to be directly below the vehicle CB. The equations to be solved become:

Static Moment Summation

$$M_{Tot} = BAGWT * XBAG + WBS * XBS + WSS * XSS + WBA * XBA + WEMISC * XEMISC + WFINS * XFINS + WLNDGR * XLNDGR + WENGT * XENG + (WCAR + UL + WPRESS + WSYSTS) * (XCARF + .5 * CARLTH)$$

$$W_{Tot} = BAGWT + WBS + WSS + WBS + WEMISC + WFINS + WLNDGR + WENGT + WCAR + UL + WPRESS + WSYSTS$$

= Maximum Take Off Gross Weight, WGROSS

By assumption / constraint:

$$\frac{M_{Tot}}{W_{Tot}} = CG = CB$$

Since CB is known from geometry routine, the only unknown is XCARF, ie, the forward or starting point of the car, point 4 in Figure 5-1. The above equation is solved for the starting point of the car, thus defining all configuration details for the two engine configuration.

Four Engine Configuration

For a four engine configuration three assumptions are made regarding the location of the four engines:

1) The maximum possible separation of the forward and aft engines is desired in order to maximize their moment capability and minimize potential propeller slipstream interference.
2) The forward and aft engines are located an equal (longitudinal) distance from the CB (DXENGF = DXENGA, see Figure 5.2).
3) The maximum magnitude of DXENG is constrained by assuming that the engine CG (and thrust center) is at the midpoint of the least forward or aft one tenth section of the car (ie, DXENGA in Figure 5.2).

With the above assumptions and some algebraic manipulation, it can be proved that the two engine static moment summation is also valid for the four engine configuration and is therefore used to define XCARF, DXENGA, and DXENGF.

Three Engine Configuration

The key assumption for the three engine configuration is that the stern engine CG and effective thrust moment arm is located a distance of one half the propeller diameter plus one foot aft of the stern of the envelope. That is:

$$DXENGA = L_{Total} - X_{CB} + .5\ Dprop + 1.0$$

Where Dprop = the propeller diameter.

The forward engines are centered on the forward one tenth section of the car (ie, 0.05 * CARLTH aft of the forward point of the car, XCARF). Therefore,

$$XENGF = XCARF + 0.05 * CARLTH$$

and

$$DXENGF = X_{CB} - XENGF$$

With these values, the longitudinal static moment summation can again be reduced to a single unknown, XCARF, and solved to define the total configuration geometry.

<u>Vertical Plane Equations</u>

The approach to solving the vertical plane equations for the two, three, and four engine static moment summation was similar to the horizontal plane analysis. The key results of the vertical plane analyses are determination of the vertical separation of the CB and CG (typically referred to as the "BG") and the "Y" value of the engine thrust moment arms.

Solution of the static balance equations required additional detail for the effective moment arms of the weight groups and subgroups.

Vertical Plane Moment Arms

Weight and balance reports for the previously listed three vehicles were analyzed to derive average values of the "Y" moment arms as well as other configuration details for future use.

The resulting values, normalized with respect to the maximum vehicle diameter are as follows:

YSC = 0.0163

YBA = 0.3288

YEMISC = 0.2238

YPRESS = 0.5032

YFINS = 0.0 (for four fin configuration)

YFINS = 0.06 (for inverted Y configuration)

Based on the assumption that the car weight and useful load following are uniformly distributed throughout the car volume, other Y component moment arms are:

$$YCAR = \left[(Dmax/2) + 7.\right] / Dmax$$

$$YUL = YCAR$$

$$YLNDGR = \left[(Dmax/2) + 7. + 3.\right] / Dmax$$

The landing gear will be assumed to provide a five foot distance between the ground line and the exterior bottom of the car. The CG (vertical plane) of the landing gear will be three feet below the car. The present analysis will make no distinction between 1, 2, and 3 wheeled landing gear configurations. The main gear will be located beneath the CB and the effective moment arm in the horizontal plane will be assumed to be equal to the CB.

$$YENG = \left[(Dmax/2) + 7. \right] / Dmax$$

This value of YENG is used for both two and four engine configurations and is also used for the two forward engines of the three engine configuration. The stern engine of the three engine configuration is assumed to have a "Y" moment arm of zero.

Note that Dmax has been used as an approximation for the actual envelope diameter in the car attach region. The car height is taken as fourteen feet.

The envelope and bow stiffening are assumed to be axisymmetric with respect to the vehicle centerline axis and, therefore, produce no moment about the CB.

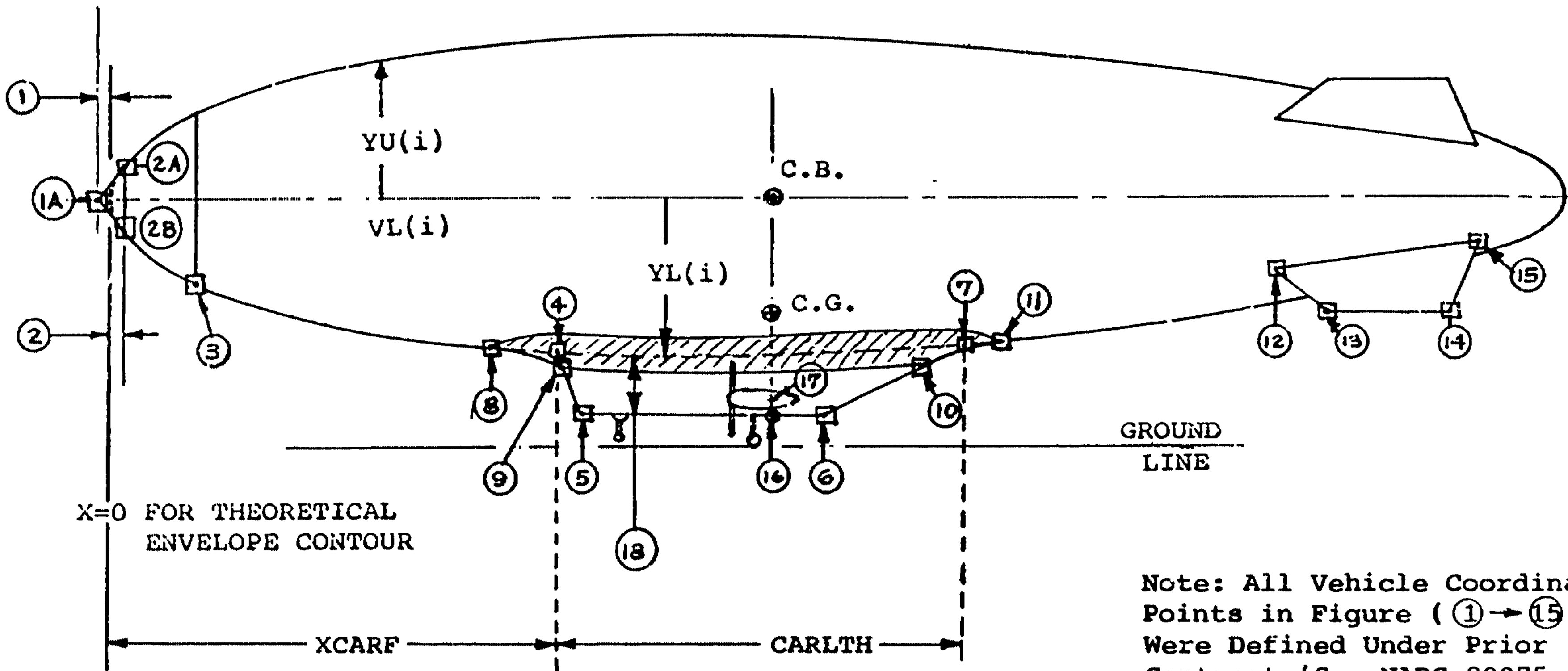
With the above assumptions and data, the vertical plane static balance equation can be solved for the location of the CG for all three configurations. The general equations are:

$$M_{Tot_Y} = WSS * YSS + WBA * YBA + WEMISC * YEMISC + WCAR * YCAR + UL * YUL + WPRESS * YPRESS + WFINS * YFINS + WLNDGR * YLNDGR + WENGF * YENGF + WENGA * YENGA$$

The vertical distance of the CG from the CB is:

$$BG = M_{Tot_Y} / WGROSS$$

With all of the static weight and balance equations solved, the data necessary to analyze vehicles in steady state towing operations is completed.



Note: All Vehicle Coordinate Points in Figure (1 → 15) Were Defined Under Prior Contract (See NADC-80075-60)

FIGURE 5-1 TWO ENGINE CONFIGURATION DETAILS

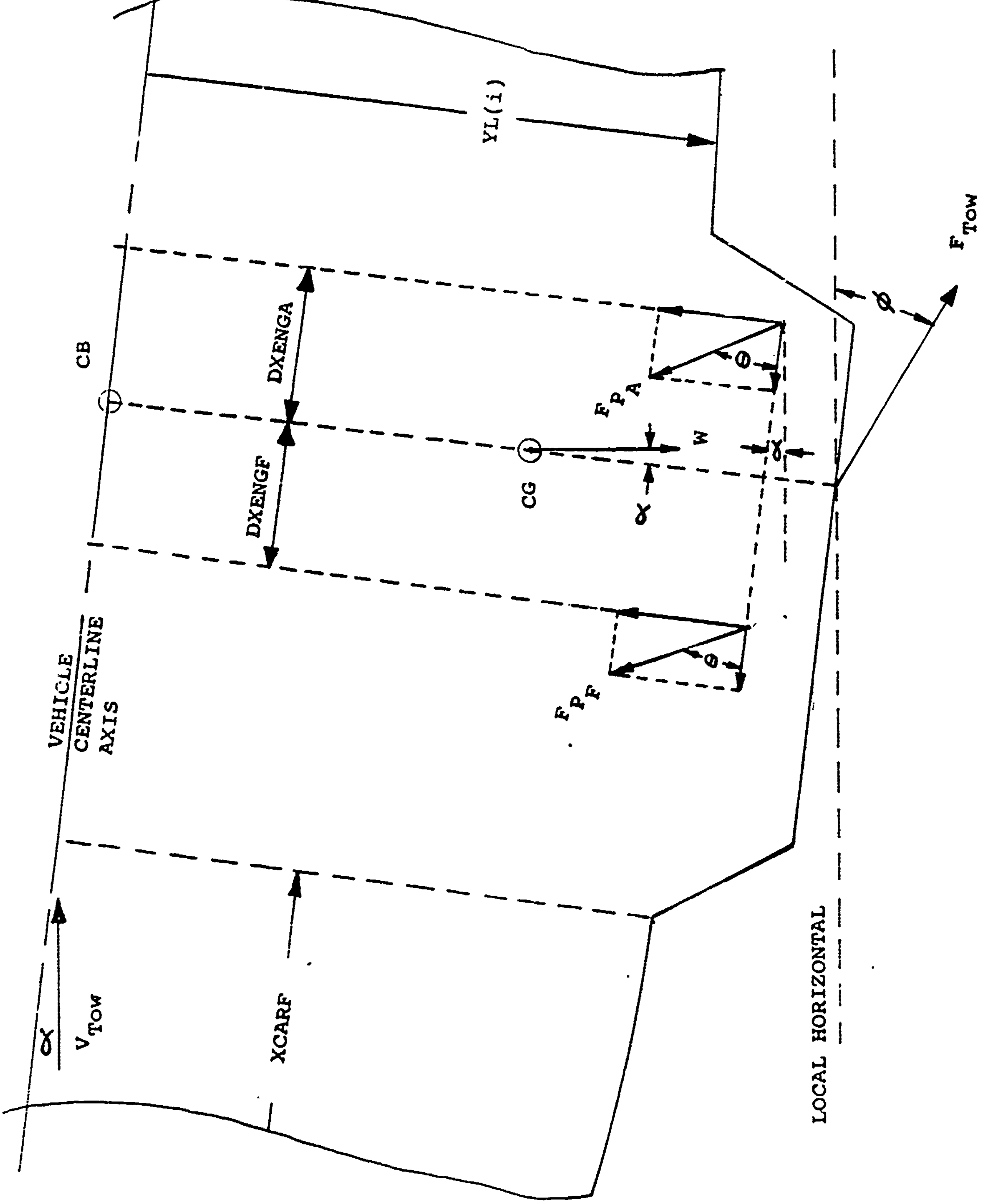


FIGURE 5-2 FOUR ENGINE CONFIGURATION DETAILS

6.0 STEADY STATE TOW MISSION PERFORMANCE EVALUATION

This task was one of the major development objectives of the current contract effort. The aerodynamics and static balance/thruster location results described in the preceeding sections provide necessary inputs required to evaluate airship towing performance (in detail) as a part of the mission profile performance evaluation option of the NAPSAP program.

The new segment type is SEGTYP = 6 for this type of mission profile segment. The existing input for tow drag force is utilized to input the tow force on the segment. The angle that the tow force vector makes with the local horizontal, ϕ, is input in the same input position as the weight transfer variable SWTSFR(i). This angle is input in degrees.

The tow segment calculations require considerable vehicle configuration detail which, at present, can only be calculated for two, three, or four engine configurations.

Towing Equations

The equations which must be solved consist of two force equations and one moment equation: Specifically,

Horizontal Force

$$F_{p_H} - D - F_{Tow_H} = 0$$

Vertical Force

$$F_{p_V} - H + L - F_{Tow_V} = 0$$

where:

F_{p_H} = the horizontal component of the propulsive (thrust) vector.

F_{p_V} = the vertical component of the propulsive (thrust) vector.

H = the total vehicle instantaneous heaviness at the start of the "j" segment calculation.

The NAPSAP variable in subroutine MISPFL is SHEAVY(J) (see Reference 1).

L = aerodynamic lift at the segments altitude, SALT(i), airspeed, SVEL(i) and the vehicle angle of attack.

D = aerodynamic drag at SALT(i), SVEL(i) and the vehicle angle of attack.

F_{Tow_H} = the horizontal component of the tow force vector.

F_{Tow_V} = the vertical component of the tow force vector.

These equations are expanded for solution as follows: (see Figure 6.1):

$$F_{p_H} - D - F_{Tow_H} = 0$$

$$(F_p)(\cos(\Theta + \alpha)) - \text{Drag} - F_{Tow} \cos \phi = 0$$

where

$$\text{Drag} = \left[C_{D_o} + K(C_{L_\alpha}(\alpha))^2 + \left(dC_d / d\delta_e\right)\delta_e\right] qV^{2/3}$$

F_p = total propulsive thrust

F_{Tow} = tow force (as input)

ϕ = angle of tow force vector with respect to the local horizontal (as input positive downward)

α = vehicle angle of attack (positive nose up)

δ_e = rudder deflection angle (positive for down deflection)

θ = thrust vector angle referenced to the vehicle centerline axis (positive for upward deflection: $\theta = 90^\circ$ and $\alpha = 0$ would produce only vertical propulsive thrust)

The vertical force equation can be expanded as follows:

$$L - H + F_{p_V} - F_{Tow_V} = 0$$

$$\text{Lift} - \text{Heavyness} + F_p \sin(\theta + \alpha) - F_{Tow} \sin\phi = 0$$

where:

$$\text{Lift} = \left[C_{L_\alpha}(\alpha) + C_{L_{\delta_e}}(\delta_e) \right] qV^{2/3}$$

Heaviness = instantaneous vehicle heaviness at the start of a given iteration of the segment type 6 evaluation.

Solution Approach and Assumptions:

With a few assumptions, the above equations can be combined to solve for the total propulsive thrust required, F_p, and the thrust vector deflection angle, θ.

An iterative approach is used to determine the minimum fuel rate combination of α, δ_e, and θ. The above equations are solved at one degree increments starting at $\alpha = 10^\circ$ and ending at $\alpha = 0^\circ$. At each α, δ_e combination, the equations are solved for Θ and F_p. The value of F_p defines the number of engines which must be used, the horsepower and throttle setting required. From these, the fuel flow rate can be calculated.

Since there are more independant variables than equations (four - α, δ_e, Θ, F_p) a simplifying assumption is required. The assumption which is made is that an elevator deflection angle is used which statically trims the vehicle aerodynamically at the given value of α.

From the analysis of prior vehicle aerodynamic characteristics, the approximation which is used is:

$$\delta_e \text{ Static Trim} \cong 2 * \alpha$$

With this assumption, it is noted that for a given segment altitude, SALT(i) and speed, SVEL(i) the equations can be simplified to terms independant of α and δ_e and dependant on α and δ_e for the iterative solution; ie,

$$F_p \cos(\Theta + \alpha) = K_H$$

$$K_H = \text{Drag} + F_{Tow_H}$$

$$F_p \sin(\Theta + \alpha) = K_V$$

$$K_V = \text{Heaviness} + F_{Tow_V} - \text{Lift}$$

by algebraic manipulation, Θ and F_p can be solved for as follows:

$$\cos(\Theta + \alpha) = K_H / F_p$$

$$\sin(\theta + \alpha) = K_V / F_p$$

$$F_p = (K_H^2 + K_V^2)^{\frac{1}{2}}$$

$$\theta = \arccos (K_H / F_p) - \alpha$$

The required horsepower is solved for simply from the relationship:

$$HP_{Req'd} = F_p * SVEL(i) / 550 * \eta_p$$

where:

η_p = the propeller efficiency at the input value of segment tow speed, SVEL(i)

From the HP required and known value of HP available, the number of engines which must be operating is determined and the throttle setting calculated. From these, the fuel rate at this "J" iteration α, δ_e combination is calculated including throttle performance, speed and altitude effects (see Reference 1).

The above calculations apply to all engine configurations - two, three and four.

These calculations are performed iteratively from 0° to 10° angle of attack with the resulting values of θ, F_p, number of engines required and fuel rate stored for further analysis in the moment balance analysis.

Moment Balance Equations

Solution of the steady state moment equations is performed simultaneously with the force equations above and is somewhat different for the two, three and four engine configurations.

The general approach used is to solve the moment equations assuming the ballonet air is uniformly distributed about the vehicle CB and that a combination of engines is used which minimizes any static moment unbalance. Then, a check is made to determine if the static moment capability which can be produced by ballonet differential is capable of trimming the vehicle.

If a total vehicle static moment balance can be achieved via ballonet differential then this iterations α, δ_e combination is a valid solution; ie, the vehicle could operate in a steady state towing mode at this iteration value of α, δ_e, F_p, and θ.

If ballonet differential cannot trim the vehicle, then a moment unbalance ratio is calculated as an indicator of the difficulty in operating at this α, δ_e combination. The ratio used is:

$$M_{Ratio} = (M_{Unb} - M_{B-Diff}) / M_{B-Diff}$$

where:

M_{Unb} = the total (minimum) static moment unbalance which occurs at the given α, δ_e with uniform ballonets and with the optimum combination of forward and/or stern (aft) engines thrusting.

M_{B-Diff} = the maximum static moment which can be produced from ballonet differential.

The moment which can be produced by ballonet differential is approximated on the following basis. The amount of ballonet air which is present at the tow segment altitude, SALT(i) is calculated from the ballonet sizing altitude HDES + DHDES (see Reference 1).

A new input variable, BALARM is utilized as the effective moment arm of the ballonets. If no value is input, NAPSAP uses a value of 0.15 of the total vehicle length.

Due to the powerful effect the ballonet differential has on the steady state towing performance, the value of BALARM appears to be a very significant vehicle design variable for vehicles to be used for towing operations.

The indicator, M_{Ratio} is used to pick the "optimum" α, δ_e combination if no α, δ_e combination is found to produce a statically trimmable situation.

The equations which are solved at each α, δ_e combination are:

$$M_{aero} + M_{Tow} + M_p + M_{Static} = M_{Unb}$$

With the simplifying assumption that δ_e is the δ_e that statically trims the vehicle aerodynamically (ie, $M_{aero} \equiv 0$), this equation simplifies to:

$$M_{Tow} + M_{Static} + M_p = M_{Unb}$$

where:

M_{Tow} = moment due to the tow force. Since the tow attach point is assumed to be directly below the CB, this moment is simply,

$$= F_{Tow}\ (\cos\phi)\ Y_{Tow}$$

where:

Y_{Tow} = the tow force moment arm

M_{Static} = the metacentric moment at the given α

$$= W_{Gross} * BG * \sin\alpha$$

where:

W_{Gross} = the vehicle instantaneous gross weight at the start of the tow segment "J" iteration (see Reference 1)

BG = the distance between the vehicle CB and CG

M_p = the total effect of moments on the vehicle due to the propulsive thrust vectors

The propulsive (thrust) moments are unique for each of the two, three, and four engine configurations. These equations are as follows:

Two Engine Configuration

$$M_p = F_p * \cos(\theta) * YENG$$

where:

YENG = the engine moment arm in the vertical plane

The moment due to the vertical thrust component is zero.

Three Engine Configuration

$$M_p = F_{p_E} * NENGS_F * \cos(\theta) * YENG + F_{p_E} * NENGS_F * \sin(\theta) * DXENGF + F_{p_E} * NENGS_A * \sin(\theta) * DXENGA$$

where:

F_{p_E} = the thrust per engine

$NENGS_F$ = the number of engines forward of the CB which are operating

$NENGS_A$ = the number of engines aft of the CB which are operating

YENG = the forward engines moment arm in the vertical plane

DXENGF = the horizontal plane moment arm of the forward engines

DXENGA = the horizontal plane moment arm of the aft engine

The above equations are solved with different combinations of engines operating with the "optimum" (lowest static moment unbalance ratio, M_{Unb}) combination being stored for further analysis in the determination of the minimum fuel rate α, δ_e, M_{Unb} combination.

The combinations which are evaluated depend on the number of engines which are required:

Number of Engines Req'd	Combinations Evaluated
one	one forward, one stern
two	one forward and one stern
	two forward
three	all engines operating

Four Engine Configuration

The same equations for the three engine configuration can be utilized for the four engine configuration evaluation. Depending on the number of engines required, the following combination of engines are evaluated to determine the combination which minimizes any moment unbalance.

Number of Engines Req'd	Combinations Evaluated
one	one forward, one aft
two	one forward, one aft
	two forward
	two aft
three	two forward, one aft
	two aft, one forward
four	all engines operating

Output Options

A new output control variable has been added to control the output of the alpha loop iteration calculations of towing performance. This control variable is the integer TOWPRT. Following are the options that may be exercised.

TOWPRT	Output Produced
0	No print out of ALPHA/DELTA iteration loop calculations
1	Print every fifth "J" iteration results of the ALPHA/DELTA calculations
2	Print all ALPHA/DELTA calculation results on every "J" iteration calculation

A sample of the NAPSAP output for one ALPHA/DELTA iteration calculation is shown in Table 6.1(taken from a remote input/output terminal printout). The NAPSAP printout variables in the Table are as follows:

L - Alpha loop control integer

ZALF - Angle of attack

Theta - Thrust vector deflection angle

NEFWD - Number of forward engines operating

NEAFT - Number of aft engines operating

THRTLK - Throttle setting of each engine

TTHRUST - Total propulsive thrust

ZLIFT - Total aerodynamic lift

ZDRAG - Total aerodynamic drag

HEAVY - Instantaneous heaviness at the start of the "J" segment

ZHPREQ - Horsepower required at the alpha/delta combination

ZFULRT - Fuel rate required (lbs/hr) at this alpha/delta combination

L	ZALF	THETA	NEFWD	NEAFT	THRTLK	TTHRUST
1	10.0	3.54	0.	1.00	.273	.208E+04
2	9.00	14.7	0.	1.00	.273	.208E+04
3	8.00	25.3	0.	1.00	.282	.215E+04
4	7.00	34.8	0.	1.00	.300	.229E+04
5	6.00	43.1	0.	1.00	.325	.248E+04
6	5.00	50.0	0.	1.00	.355	.271E+04
7	4.00	55.8	0.	1.00	.389	.297E+04
8	3.00	60.8	0.	1.00	.426	.324E+04
9	2.00	65.0	0.	1.00	.464	.354E+04
10	1.00	68.6	0.	1.00	.504	.384E+04
11	0.	71.8	0.	1.00	.545	.416E+04

ZLIIFT	ZDRAG	HEAVY	ZHPREQ	ZFULRT	MOMUNBAL
.346E+04	.116E+04	.345E+04	232.	199.	0.
.312E+04	.104E+04	.345E+04	232.	199.	0.
.277E+04	930.	.345E+04	240.	204.	0.
.242E+04	839.	.345E+04	255.	215.	0.
.208E+04	757.	.345E+04	276.	229.	0.
.173E+04	687.	.345E+04	302.	245.	0.
.138E+04	624.	.345E+04	331.	263.	0.
.104E+04	566.	.345E+04	362.	281.	0.
692.	516.	.345E+04	395.	300.	0.
346.	471.	.345E+04	429.	318.	0.
0.	430.	.345E+04	464.	336.	0.

ISEG	J	SVEL	HPREQ	NENG	THRTLK	FUPT	WFC
3	2	33.778	231.77	1.0000	.54537	198.84	49.71

HEAVY	DHEAVY	TWF	FLBURN
3449.4	99.762	99.762	244.41

TABLE 6.1 ALPHA/DELTA ITERATION RESULTS

MOMUNBAL - Moment unbalance at this alpha/delta combination. Note, a value of zero indicates that ballonet differential can trim the vehicle in this alpha/delta combination.

The printout following the alpha/delta loop results are the values of performance variables utilized for the "J" segment calculations (output if TPRINT is input = 2), (see References 1 and 2). These NAPSAP variables are as follows:

- ISEG - Mission profile input segment number
- J - Iteration loop control integer
- SVEL - Segment input airspeed in knots
- HPREQ - Horsepower required for the "J"th iteration of this "I" segment
- NENG - Number of engines operating
- THRTLK - Throttle setting of each engine
- FURT - Fuel flow rate on the "J" iteration
- WFC - Total fuel consumed on the "J"th iteration
- HEAVY - Heaviness at the start of the "J"th iteration
- DHEAVY - Change in heaviness on the "J"th iteration
- TWF - Total weight of fuel consumed up to this point on this I segment
- ALFREQ - Angle of attack required

Note that as the Table shows, the minimum fuel rate from the alpha/delta loop iteration is used for the fuel rate on the "J" iteration. Note also that this minimum fuel consumption does not occur at the minimum horsepower due to the interrelation of throttle setting and SFC as a function of throttle setting.

It should be noted that the detailed tow segment analysis adds a considerable amount of "number crunching" calculations to NAPSAP's evaluation of mission profile performance. This can be seen by the following example:

For a detailed tow segment, SEGTYP = 6, evaluation of ten hours (SDUR(i) = 10.) and an iteration time step of 0.1 hours (DELTJ = 0.1), NAPSAP will perform as follows:

The number of "J" iterations on the towing segment, NITER, will be (SDUR(i)/DELTJ) = 100. On each "J" segment, eleven alpha/delta iterations will be performed for a total of 1100 solutions to the steady state tow performance evaluation. If the combinations of engines operating must also be evaluated, the number of alpha/delta/"J" evaluations can double or triple.

Obviously, care should be used in picking the input value of DELTJ, TOWPRT, and TPRINT for most general sizing runs and in particular for FOMVAR = 1 type runs where NAPSAP is utilized to iterate on vehicle volume required to "exactly" satisfy the input mission profile.

Other Comments on Tow Segment Logic

The detailed tow segment evaluation logic cannot be used at this time to "size" a vehicle per se. That is, the basic NAPSAP sizing logic (Reference 1) which utilizes the maximum horsepower required for VTOL at maximum take off gross weight or cruise at the input value of design speed, VDES at maximum take off gross weight is still utilized to size the propulsion system.

However, in the analysis of U.S. Coast Guard Maritime Patrol Missions and Naval operations of airships towing sonar arrays (see References 6 and 7, respectively), the tow drag force has been found to occasionally be a critical design factor or at least a limiting factor in the airship's operational capability. It is very likely that when a sizing/performance study is initialed, a tow drag force, tow angle, heaviness condition may be called for in the mission profile which the input vehicle can not perform even with all engines operating at maximum horsepower.

In order to accomodate this situation, and still allow the NAPSAP vehicle resizing logic to converge on the required vehicle volume, an approximation has been included in the program logic to reduce the input tow speed and tow drag force to a value which the vehicle can accomodate. The logic assumes that the tow drag force can be approximated by a "K" V^2 relationship. If sufficient power (thrust) is not available at the input value of segment tow speed, the tow speed is reduced by 10% of the input value. The tow drag force is reduced proportionately (according to KV^2) and the alpha/delta loop re-evaluated until a segment tow speed is found at which the vehicle has sufficient thrust to perform and the calculations are continued. The input values of tow drag are saved for reinitialization purposes on the next vehicle resizing iteration.

Summary

The NAPSAP evaluation of vehicle towing performance described above is (to the best of Lancaster Analytic's knowledge) far more detailed than any previously available, and should provide considerable confidence in NAPSAP's evaluation capability of airships in towing operations.

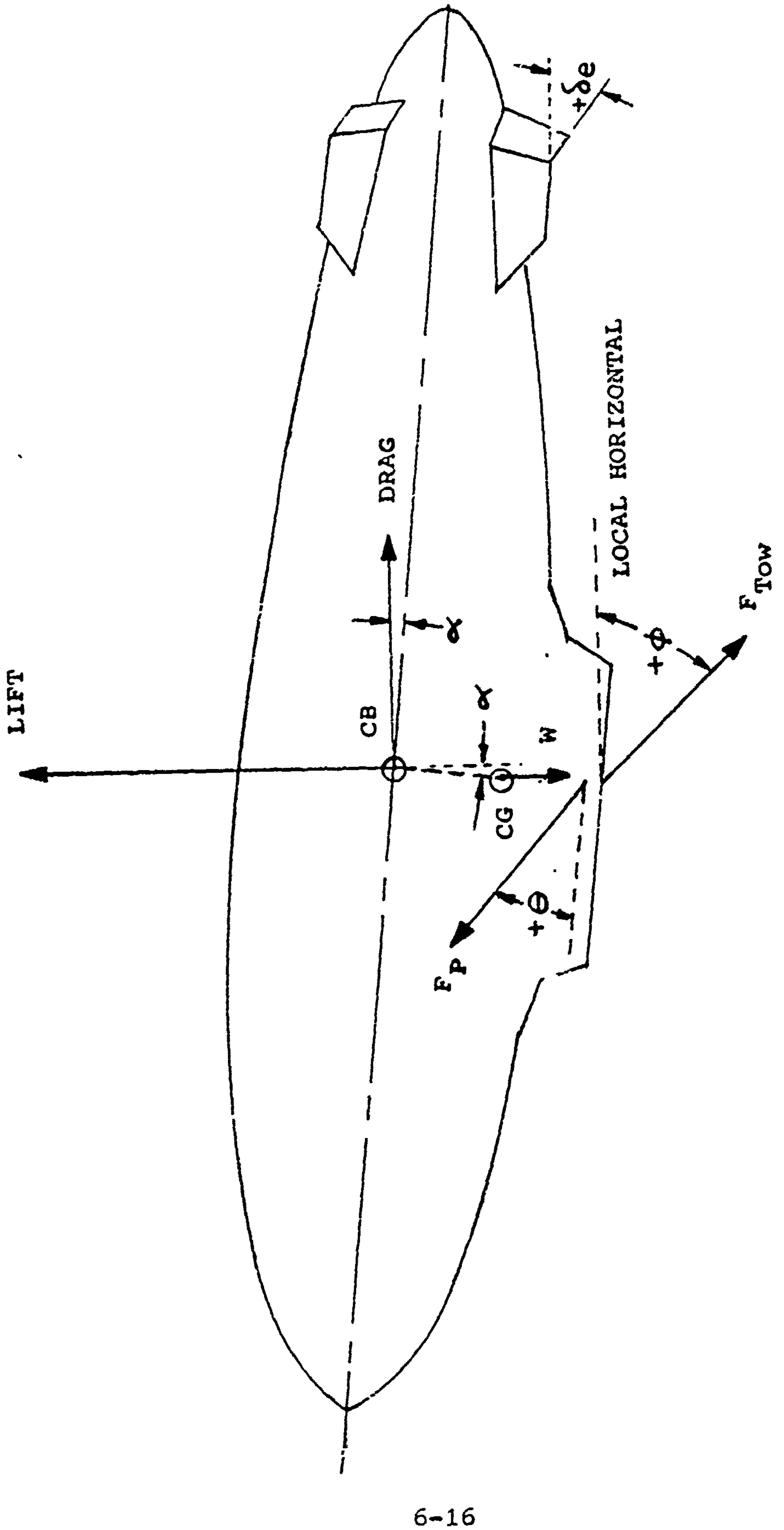


FIGURE 6-1 TOWING OPERATION FORCES AND ANGLE SIGN CONVENTION

7.0 INCLUSION OF NEGATIVE ANGLE OF ATTACK EFFECTS ON GENERALIZED PERFORMANCE AND MISSION PROFILE PERFORMANCE WITH AUTOMATIC REBALLASTING OPTION

The objective of this task was to include the (optional) capability to analyze the effects of negative angle of attack flight on vehicle performance when the vehicle becomes "light"; ie, when the static lift exceeds the instantaneous vehicle gross weight. All necessary equations, logic, and coding have been completed and are operational.

The original analysis capability (ie, assuming neutrally buoyant flight is maintained whenever the vehicle reaches a state of neutral buoyancy) has been retained as an option. The reason for retaining this option is to allow the analysis of vehicles which utilize on board ballast recovery means to maintain a neutrally buoyant state, thus allowing flight to be maintained at zero angle of attack as fuel is consumed.

This new type of evaluation is controlled by a new input control variable NBALF (for neutrally buoyant angle of attack). This integer input required a new card of input data which must now follow the first (control) card. If NBALF = 0, the program will utilize the original equations. If NBALF ≠ 0, negative angle of attack drag effects will be included in the three following performance areas:

1. Generalized performance evaluation at the input design speed (Runtyp = 0).
2. Performance evaluation at speeds below the design speed (Runtyp = 3).
3. The cruise segments of mission profile performance evaluations (Segtype 1 & 3 for RUNTYP = 2).

For the first two performance evaluation options, no limit is placed on the (negative) angle of attack required. (A limit could be included as a program option). Therefore, no reballasting is automatically performed on the generalized performance evaluation type of runs (RUNTYP = 0, and 3).

Induced drag effects are calculated via the basic program methodology (see Reference 1). Lift coefficient is assumed to be symmetrical with respect to alpha equals zero. All KF(i) sensitivity factor options can be utilized with the negative angle of attack evaluations.

Analysis of negative angle of attack flight can also be analyzed on cruise type segments (SEGTYP = 1, and 3) in the mission profile subroutine. In addition to analyzing the induced drag penalties associated with "light" flight as described above, an additional capability was incorporated into the mission profile (RUNTYP = 2) analysis capability: The capability to incorporate an automatic reballasting whenever the vehicles state of lightness exceeds that which can be sustained at an (optional) input minimum angle of attack value.

An additional input variable ALFMIN may be input as the maximum negative angle of attack allowed before the program will command a reballast. If ALFMIN is not input a value of six degrees will be used. If NBALF is input as zero (or not input) this option will be bypassed, thus still allowing the analysis capability for on board water recovery.

The new program logic utilizes the following assumptions:

1. Time required to climb and descend from the segment altitude is based on a 1500 ft/minute rate of climb and descent.
2. Time required to reballast is based on a rate of water pickup of 1000 gallons/minute.
3. The total time required over a mission profile is treated as "parasitic" or non-productive mission time and does not contribute to either the input value of mission time or time on station.
4. Multiple reballasts may be commanded on any input mission profile segment.
5. The amount of water ballast to be picked up will be equal to the amount of aerodynamic lift which can be sustained at a positive angle of attack equal to ALFMIN <u>and</u> at the given mission profile speed and altitude.

Note that by assumption #5, the amount of heaviness which is automatically taken on board can be analyzed to determine the effects on mission profile performance (hence, vehicle size). This will simply require multiple runs of NAPSAP-MISPFL with different input values of ALFMIN.

New variables added to cruise segments (SEGTYP 1 & 3) of mission profile for the automatic reballasting are as follows:

TDBLST = weight which will be picked up in the automatic rebàllast

XLMIN = the maximum amount of vehicle lightness which is allowed before an automatic reballast is instituted. XLMIN is a function of the segment velocity and dynamic pressure. XLMIN is the value (in pounds) of lift which the vehicle can develop at ALFMIN.

ALFMIN = the absolute value of the maximum negative angle of attack allowed. This variable can be input. If ALFMIN is not input a value of six degrees will be used.

CLMIN = lift coefficient at ALFMIN

XLMIN = CLMIN * Q(SVEL(I),SALT(I)) * AREF

BCNT(I) = total number of automatic reballastings performed on the ith segment.

CWBLST(I) = total weight of ballast picked up on the ith segment.

DTBLST = time in hours required for a given reballast. The time required will be automatically calculated and added to the input value of time requested for this mission segment. The time required is conservatively calculated on the basis of 1) a descent from the segment cruise altitude at 1500 ft/min., 2) refuel in an amount equal to the instantaneous lightness plus a heaviness equal to the maximum allowed lightness SLMIN, and 3) climb back to the input segment altitude at 1500 ft/min.

CTBLST(I) = the cumulative total time required for automatic reballastings on the ith segment. This time will be treated as "non-productive" mission time when calculating TOS (Time On Station), but will be added into the total mission time (TMIST).

GTNRBS = total number of automatic reballastings for the entire mission profile.

GTTBLST = total time spent in reballasting for the entire mission profile.

The program prints out a summary of automatic reballasting activity which includes the number of automatic reballasts executed, the total (water) ballast which was picked up, and, the total amount of time required for reballasting over the entire mission profile.

The effects of flight at negative angle of attack will be strongly dependent on the specific nature of the mission profile. On one representative MPAS type mission profile of 112 hours duration, the vehicle volume required to satisfy the mission increased by seven percent due to negative angle of attack effects.

8.0 SUMMARY OF NAPSAP STATUS AS OF OCTOBER 1982

NAPSAP, the Naval Airship Program for Sizing And Performance, has been developed to assist the U.S. Navy's Lighter Than Air Project Office at the Naval Air Development Center in their continued analysis of the technical and operational feasibility of modern LTA vehicles. NAPSAP can perform preliminary design and parametric performance analysis of rigid or non-rigid LTA vehicles, utilizing gas turbines, diesels, or gasoline powered reciprocating engines, in conventional take-off or VTOL operations.

NAPSAP has been designed to operate with a minimum of required input data but has the capability of analyzing the influence of over 40 key design and/or operational parameters. Program capabilities include the following:

I) Point design vehicle sizing and performance evaluation at constant speed and altitude.

II) Performance evaluation of the Point Design vehicle at speeds below the design speed.

III) Parametric analysis of a Point Design vehicle sizing and performance as a function of the perturbation of key design or operational parameters.

IV) Performance evaluation of a Point Design vehicle over complex mission profiles characteristic of U.S. Coast Guard Maritime Patrol and U.S. Navy Operational missions. The mission profiles may contain 200 segments. Each segment may consist of one of six different types of operations:

1) cruise for a fixed time
2) hover for a given time
3) cruise for a given range
4) pickup or off load payload
5) refueling
6) towing operations

The mission profile performance evaluation may include the effects of mission dependant expendables, auxiliary power, towing forces, and ballast requirements.

V) An important analysis feature of NAPSAP is the capability of the program to perform multiple iterations of the vehicle sizing and mission profile performance evaluations with vehicle resizing to determine the minimum vehicle volume required to satisfy the input mission profile performance characteristics.

The effects of steady or quasi random winds may be evaluated as a part of the mission profile calculations.

The current contract effort has resulted in a significant advancement in the level of detail with which NAPSAP can analyze two, three, and four engine non-rigid airships. Program capabilities for these vehicles now include detailed weight and balance calculations, complete definition of the geometrical details associated with the car and propulsion systems, and detailed evaluation capability of towing type operations in Subroutine Mission Profile.

This detailed tow segment performance evaluation option includes analysis of the forces and moments associated with the vehicle in a steady state towing operation.

Another significant accomplishment of the current contract effort was incorporation of the (optional) capability to analyze the effects of flight at negative angles of attack when the vehicle becomes "light".

Although many approximations and simplifications are utilized in the NAPSAP program methodologies, the program's level of detail is approaching that of a preliminary design program. Several of the key areas deserving further development activity are discussed in the following section.

However, the current NAPSAP program development objectives have been satisfied. The U.S. Naval Air Development Center now has a computer program operational on their Center computer system which can perform rapid evaluations of the technical and operational feasibility of modern LTA vehicles over a broad spectrum of operational missions. This computer tool has proved to be extremely useful in support of the Maritime Patrol Airship Study (Reference 6) and the evaluation of airships as advanced towed array vehicle platforms (Reference 7). Completion of a detailed technical reference document on the program methodologies and a detailed user's manual with numerous example runs will make the NAPSAP program a valuable analytical tool with which the LTA (and non-LTA) communities may fully explore the operational utility and mission effectiveness of airships for a variety of Navy missions.

9.0 RECOMMENDATIONS

In reviewing the overall program status, the program is nearly in a state to provide a very credible starting point for more rigorous and detailed point design studies. Certainly the program provides the NADC LTA Project Office with an extremely flexible analytical tool to quickly evaluate the key design and operational trade off's of LTA vehicles for missions of interest.

It is LANCASTER ANALYTIC'S recommendation that several minor additional capabilities should be incorporated into the program and then documented in detail in technical report and user's manual. The user's manual should provide several sample runs complete with input data descriptions and analysis of the output results such that virtually anyone could obtain a copy of the program, and produce meaningful, understandable results.

LANCASTER ANALYTICS would suggest that the above be accomplished in a follow-on program effort and all documentation be completed in order to present the program to the LTA technical community at the July 1983 LTA Conference.

This would appear to offer the LTA Project Office with the opportunity to provide the LTA (and non-LTA) technical communities with an analysis tool sufficient to support mission evaluation studies: Herein lies the program's greatest worth - to find out how well airships can perform Navy missions.

LANCASTER ANALYTICS envisions this documentation being on a par with that of HESCOMP, VASCOMP, and similar large scale computer program documentation/user's manuals.

In reviewing the recommendations in Reference 2, the other areas which appear worthy of further development include the following:

1) Completion of the computerized graphic output of computation results and vehicle configuration drawings (currently partially completed and underway via Rich Adams at NADC).
2) Inclusion of vehicle cost estimating relationships (RDT&E, acquisition and life cycle cost). Equations for rigids are available (see Appendix B).
3) Inclusion of an automatic sensitivity option to both the basic case and to mission profile performance evaluations. Currently, NAPSAP can automatically perform Beta sensitivity and below design speed performance evaluations for converged vehicles. Automatic sensitivity studies using the KF(i) option would be useful in identifying parameters.
4) Completion of the effort to develop a multi-variable optimization capability (currently underway at NADC).
5) Addition of cruise speed to and from station perturbations to MISPFL iteration options. (Can be accomodated by item 5 results or multiple NAPSAP runs.)
6) Static weight and balance calculation to include envelope stress effects (weight and balance completed).
7) Addition of stern propeller performance and unequal engine horsepower combinations to the propulsion performance methodology.

8) Inclusion of off-standard atmosphere effects on vehicle performance (statics, aerodynamics, and propulsion).
9) Revision of the weight estimating relationships, WER's, to reflect more advanced state of the art design and materials technology particularly for the envelope, car, and fins of non-rigid vehicles.
10) Inclusion of climb and descend mission profile segments.
11) Addition of a complete "SAC chart" type performance output option.

Other Program Developments Which May Be Of Interest
(depending on NADC's needs envisioned during next several years)

12) Inclusion of ANVCE Semi Air Buoyant type vehicles using WER's and the aerodynamics methodology from Reference 6 (Bailey, D.B. & Rappoport, H.K.,: "Maritime Patrol Airship Study (MPAS)", NADC Report No. 80149-60).
13) Inclusion of multiple engine cycles (diesels, gas turbines) on the same vehicle sized for specific portions of an operational mission profile (tow, dash, loiter, etc.).
14) Vehicle sizing based on minimum total fleet (life cycle) cost.
15) Inclusion of Sandwich shell monocoque and metal clad vehicles.

10.0 REFERENCES

1) Lancaster, J.W.,: "Naval Airship Program for Sizing And Performance - NAPSAP - Computer Program Development Final Report", NADC Report No. 79206-60, January 1980.

2) Lancaster, J.W.,: "Naval Airship Program for Sizing And Performance - NAPSAP - Computer Program Development - Program Update", NADC Report No. 80075-60, September 1982.

3) Bailey, D.B. & Lancaster, J.W., "Naval Airship Program for Sizing And Performance (NAPSAP)", AIAA Paper No. 80-0817, May 1980.

4) Lancaster, J.W.,: "Feasibility Study of Modern Airships - Phase I - Volume IV - Appendices", NASA CR-137692, August 1975.

5) Lancaster, J.W.,: "ANVCE - ZPG-X Point Design Study", NADC Contract N62269-76-M-4325, March 1978.

6) Bailey, D.B. & Rappoport, H.K.,: "Maritime Patrol Airship Study (MAPS)", NADC Report No. 80149-60, March 1980.

7) Bailey, D.B. & Bogle, C.T., Naval Air Development Center: "Airship Towed Array System (ATAS)", AIAA Technical Paper No. 81-1308-CP, presented at the Lighter Than Air (LTA) Systems Technology Conference held in Annapolis, Md., July 1981.

APPENDIX A

INDUCED DRAG ANALYSIS

APPENDIX A: INDUCED DRAG ANALYSIS

A part of the current contract effort aerodynamic analysis included a re-examination of the NAPSAP algorithms for zero lift drag and induced drag.

Examination of NAPSAP estimated zero lift (zero angle of attack) drag coefficient agrees well (within 5% to 10%) of prior vehicles. However, an apparantly considerable discrepancy was identified in the induced drag formulation. NAPSAP has utilized the "CLASSICAL" formulation for induced drag of:

$$C_{Di} = 0.9\ C_L^2$$

The lift coefficient versus angle of attack used in NAPSAP is essentially in accordance with the ZPG-X study as shown in Figure A-1. The NAPSAP drag coefficient versus angle of attack agrees well with the extensive analysis of ZPG-X (Figure A-2). Also, from the author's personal notes, a copy of a wind tunnel test study of 1/48 scale vehicles (Figure A-3) showed a good correlation with a value of 0.9.

However, as the reference data was analyzed to develop the aerodynamic coefficients in Section 3.0, some substantial discrepancies were discovered. In the 3W performance report (GER 6915 Rev E), several statements are made to the effect that the constant of 0.9 in the equation appears somewhat low (see Page 13). This seems valid.

The report states the constant is "probably low" or page 26, but that the "complete analysis of the problem is beyond the scope of the project".

The analysis of the data in the 2W and the 3W performance reports shows that a constant of greater than 0.9 can be derived from the data presented in the reports. These results are presented in Table A-I and A-II.

These results suggest further analysis of the proper value of the induced drag "K" factor is warranted.

Note that NAPSAP has the capability to analyze the effects of higher values cf zero lift drag, induced drag and total d ag via the "KF(i)" sensitivity factor program option (see Reference 1).

TABLE A-I

Calculation of Induced Drag "K" Factor for ZPG-2W Vehicle

α	CL@ $\delta_{e=0}$	CL^2	ΔC_D	$\left(\frac{\Delta C_D}{C_L{}^2}\right) = K$
4°	.055	.003025	.0038	1.256
8°	.112	.012544	.0112	0.89
12°	.184	.03385	.036	1.06

Using C_L from Figure 6 and C_D from Figure 7 of GER 5589 Rev E.

TABLE A-II

Calculation of Induced Drag "K" Factor for ZPG-3W Vehicle

α	CL@ $\delta_{e=0}$	CL^2	ΔC_D	$\left(\frac{\Delta C_D}{C_L{}^2}\right) = K$
4°	.056	.003136	.0035	1.1161
8°	.112	.012544	.0152	1.2117
12°	.175	.030625	.037	1.208

Using C_L from Figure 42 and C_D from Figure 22 of GER 6915 Rev E.

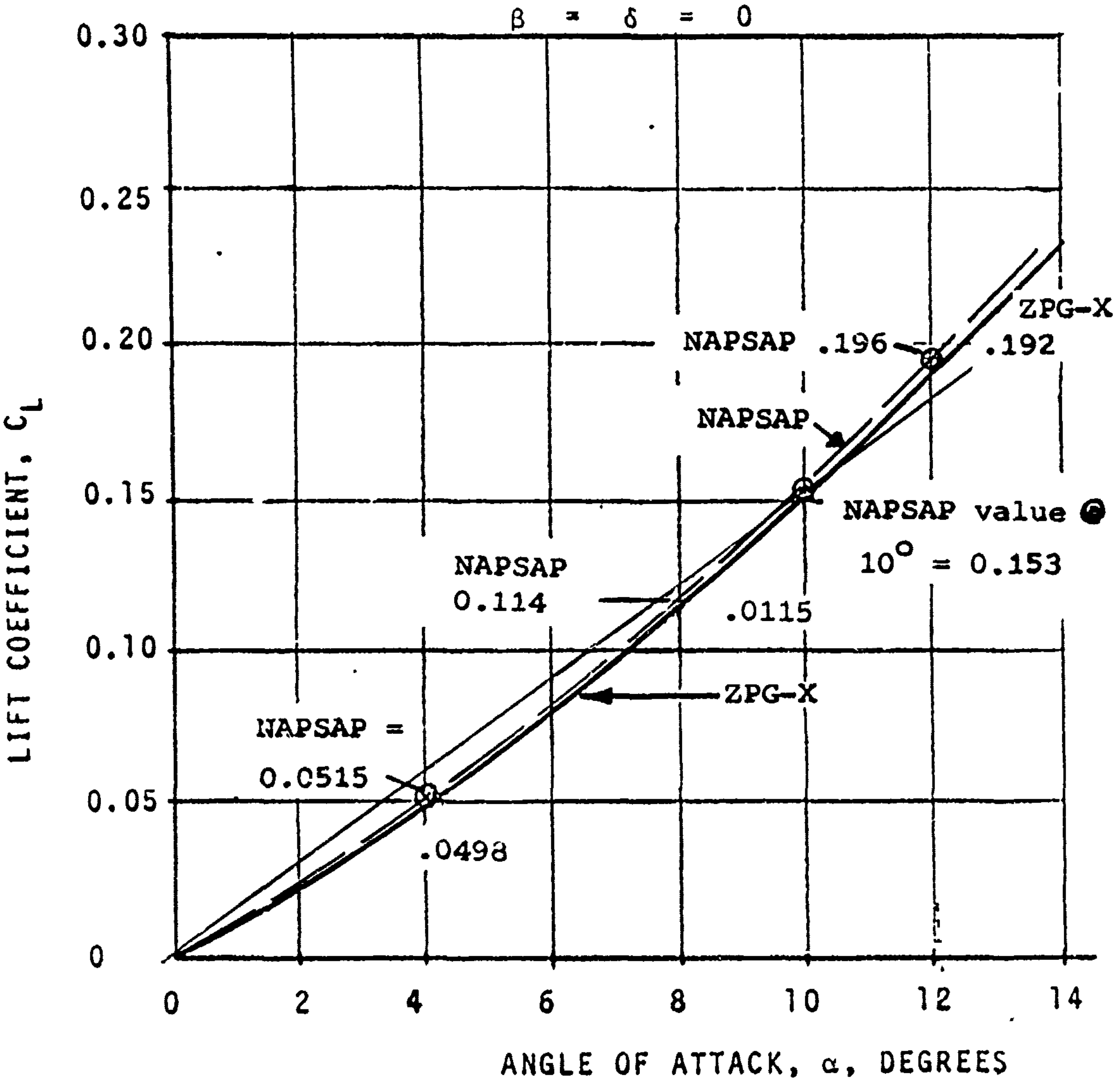


FIGURE A1: ZPG-X C_L vs. α WITH NAPSAP COMPARISON

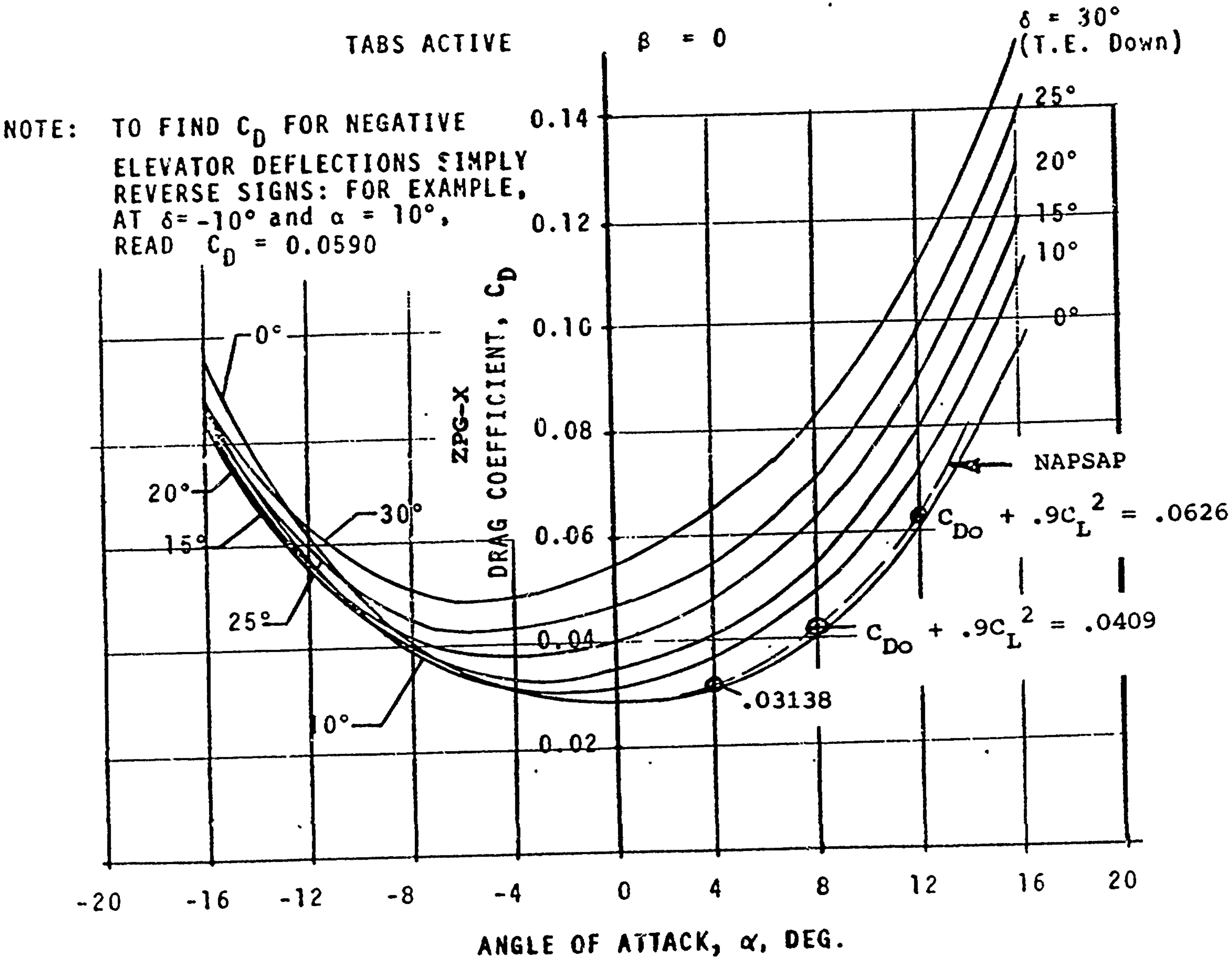
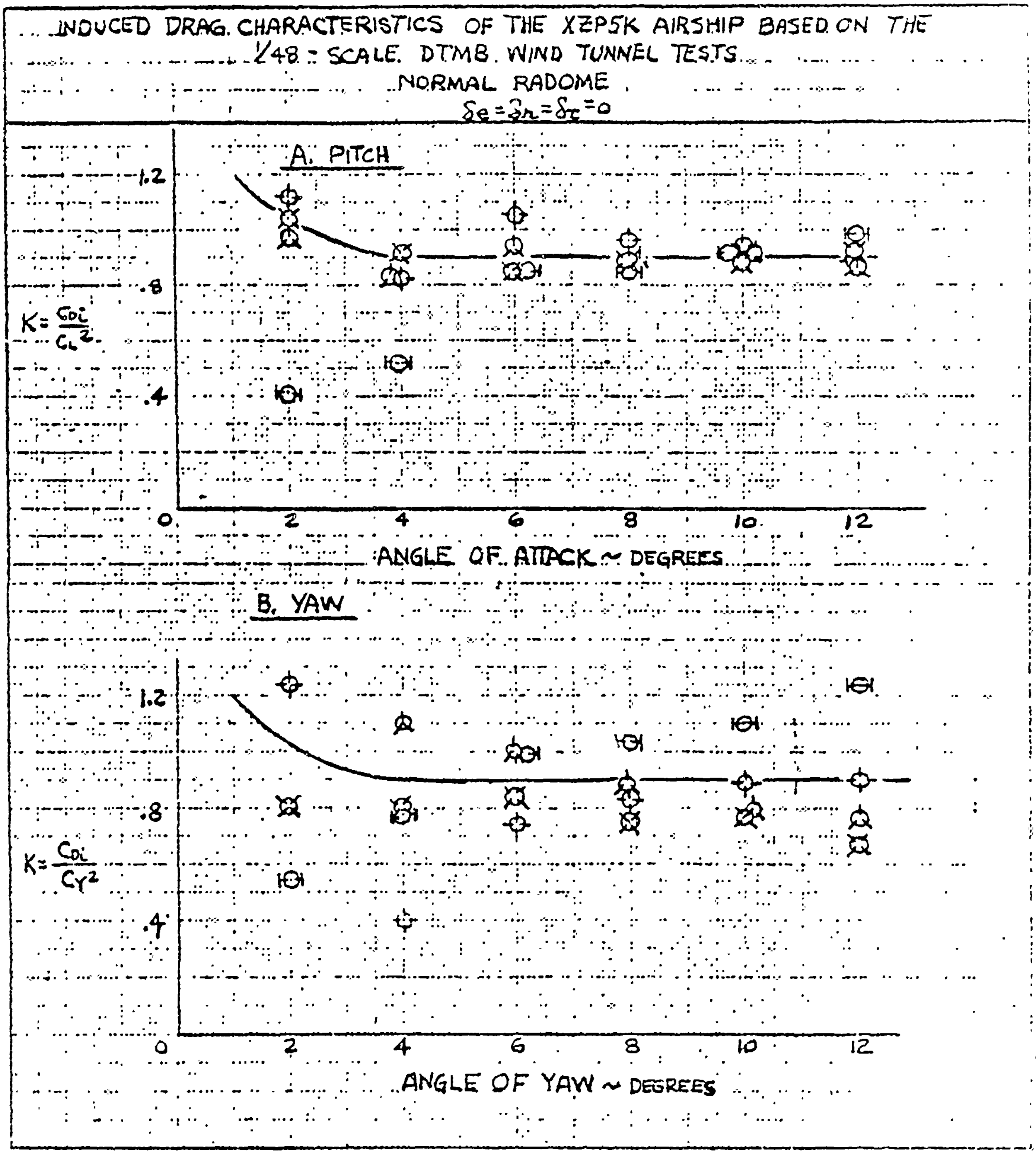


FIGURE A2: ZPG-X DRAG COEFFICIENT VS ANGLE OF ATTACK WITH NAPSAP COMPARISON

NADC-81218-60



CHARACTERISTICS OF 1/48 SCALE MODEL AIRSHIP

FIGURE A-3

APPENDIX B

RIGID AIRSHIP WER AND COST ANALYSIS

RIGID AIRSHIP COST ANALYSIS

One of the primary areas of general consultation during the current contract was in support of the NASA/Navy study of the PERU Cargo airship transportation(Ref. B-1). Several NAPSAP runs were made and analyzed in support of this effort in addition to a recalculation of rigid airship cost estimates based on the author's prior work at Goodyear, (reported in Goodyear LTA Project Memo #145). This effort, done on the author's own time, supported the critique of the ANVCE Airship cost analysis.

The current effort confirmed the statements and conclusions put forth in the project memo on upper bound rigid airship costs of 160 to 180 dollars/pound empty weight in 1977 dollars. These results are summarized in the following Table.

Vehicle weights from NADC-80075-60 (Reference 2)
Vehicle costs from JWL LTA Project Memo #145

NASA/Navy 11.2 MCF Phase II Study Rigid Airship

Component	Weight		Cost (Figure II-3)		1977 Total Cost ~ 10^6\$
Structure	246,500	@	154 \$ / Lb	=	37.961
Propulsion	15,600	@	* 140 \$ / Lb	=	2.184
Systems	22,213	@	** 210 \$ / Lb	=	4.6647
Total Empty Weight = 284,315					
Cumulative Average Unit Cost Based on Q = 50 \$/Lb Data					44.8097

* (Figure II-1) ** (Figure II-2)

Total Vehicle Cost / Lb Empty Weight, 1977 $ = $157.6
(w/o RDT&E @ Q = 50)

If spread RDT&E @ 2 times first unit cost, the following results are obtained: First find the unit cost:

Component	$/Lb		Weight		First Unit Cost ($M)
Structure	560	*	.2465	=	138
Propulsion	335	*	.0156	=	5
Systems	490	*	.022213	=	10.9
					$154 M

Therefore, RDT&E Cost = 2 * $154M = $308 * 10^6
Amount to be spread on each of 50 airships = 6.16 M$
RDT&E Cost/Lb for 50 airships quantity = $\frac{6.16}{.284}$ = 21.7 $/Lb EW

Therefore, the estimated total vehicle cost/Lb EW, including RDT&E for a production quantity of 50 airships is 179.3 $/Lb.

Note that this is an UPPER BOUND STRUCTURE COST!

The author's Project Memo actually suggested that much lower costs might be more realistic.

APPENDIX B REFERENCES

B-1) Mayer, Norman J.: "A Study of Dirigibles For Use In The Peruvian Selva Central Region", NASA, March, 1982.