SPACE SHUTTLE BOOSTER FLYBACK SYSTEM SYNTHESIS

D. W. Jones, W. J. Moran, and V. A. Lee

Convair Aerospace Division
General Dynamics Corporation
Fort Worth, Texas

SUMMARY

This paper is concerned with one particular aspect of configuration development and evaluation for an earth-to-orbit reusable space transportation system. It deals only with the first-stage booster element of the system. Furthermore, it is restricted to consideration of only those aspects of the booster which are associated with its capability to be recovered - i.e., the booster flyback system. The major portion of the discussion is concerned with a computerized synthesis approach for treating this problem. A more detailed development of the methodology is given in General Dynamics Report ERR-FW-1198, "Reusable Booster Flyback System Synthesis."

BOOSTER FLYBACK SYSTEM SYNTHESIS

(Figure 1)

The earth-to-orbit reusable space transportation system considered here utilizes a first-stage winged booster to propel a second-stage winged orbiter to part of its required mission velocity. Following staging, the booster enters the atmosphere and decelerates and turns aerodynamically toward a landing site (usually at the launch location). Then, powered by turbojet engines, it cruises to the landing site as a subsonic airplane and lands horizontally. The booster also has abort and ferry capabilities.

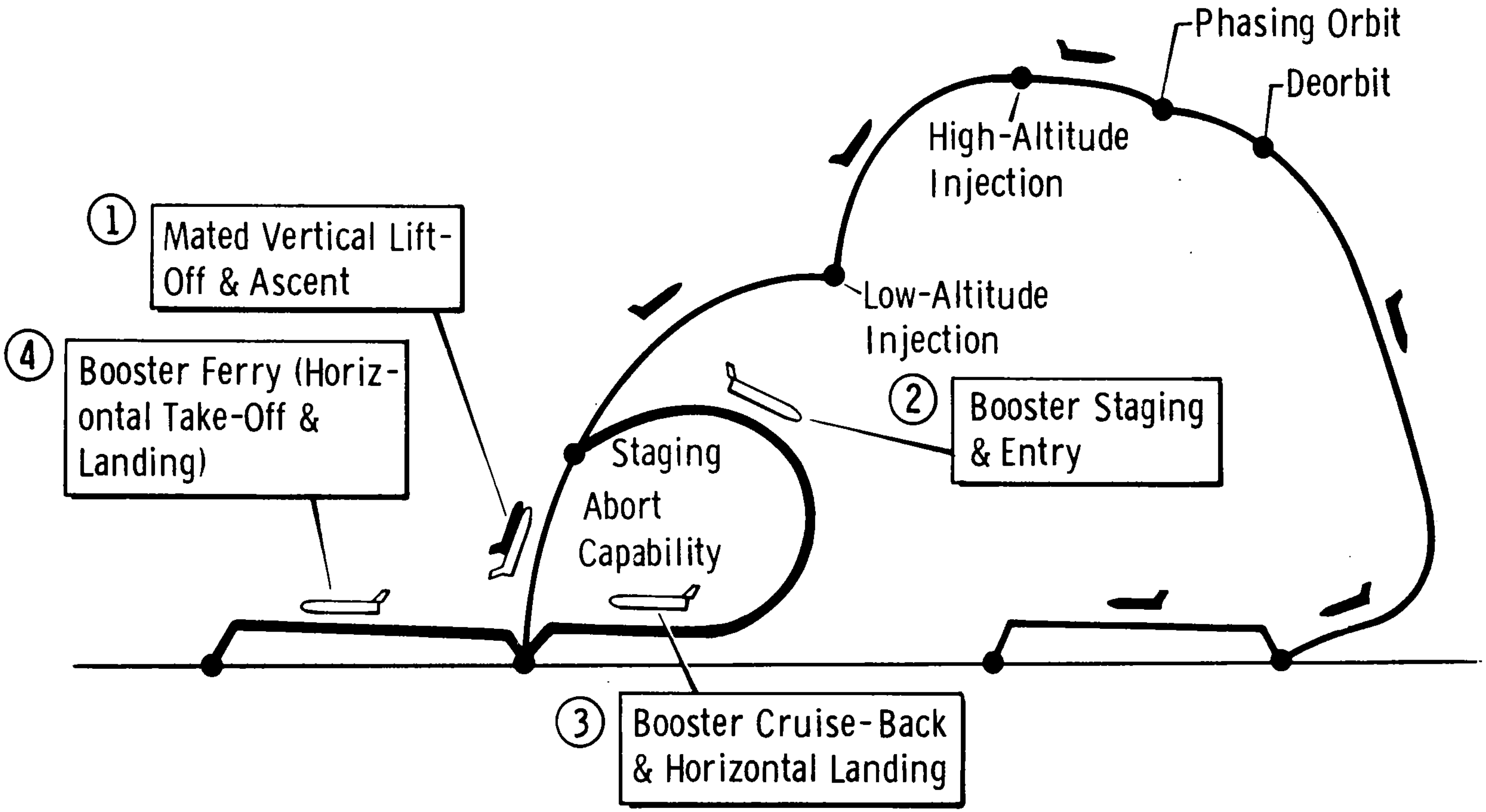
The system is configured and sized on the basis of efficiently delivering specified payloads to specified low earth orbits, and retrieving payloads from these orbits. These requirements coupled with the mission concept illustrated in the opposing figure define diverse, complex flight mechanics/ performance considerations which in turn drive the system synthesis process.

The problem of synthesizing a "good" (hopefully "best" in some sense) configuration for the booster cannot, of course, be considered out of the context of the complete system - i.e., booster plus orbiter. A total-system synthesis function is obviously required. However, a separate (but closely coordinated) detailed booster synthesis process can be effectively used to compliment a less-detailed overall synthesis effort. Moreover, for many purposes, synthesis of those booster components which relate to the flyback (post-staging) aspects of the mission can, if properly coordinated, be handled separately to good advantage. These components - wing and other aerodynamic surfaces, air-breathing propulsion, and landing gear - are termed the flyback system.

Configuration synthesis of the booster fly-back system (in combination with given booster bodies) is the problem which is considered here.

BOOSTER FLY-BACK SYSTEM SYNTHESIS

- THE BOOSTER AFTER STAGING



Phasing Orbit

Deorbit

High-Altitude Injection

Low-Altitude Injection

Staging

Abort Capability

① Mated Vertical Lift-Off & Ascent

② Booster Staging & Entry

③ Booster Cruise-Back & Horizontal Landing

④ Booster Ferry (Horizontal Take-Off & Landing)

Figure 1

A TYPICAL DESIGN

(Figure 2)

The opposing figure illustrates the fly-back system components for a typical booster design. Note that the 12 air-breathing engines are stowed in the wing during entry, and deployed at the beginning of cruise.

A TYPICAL DESIGN - Flyback System Components

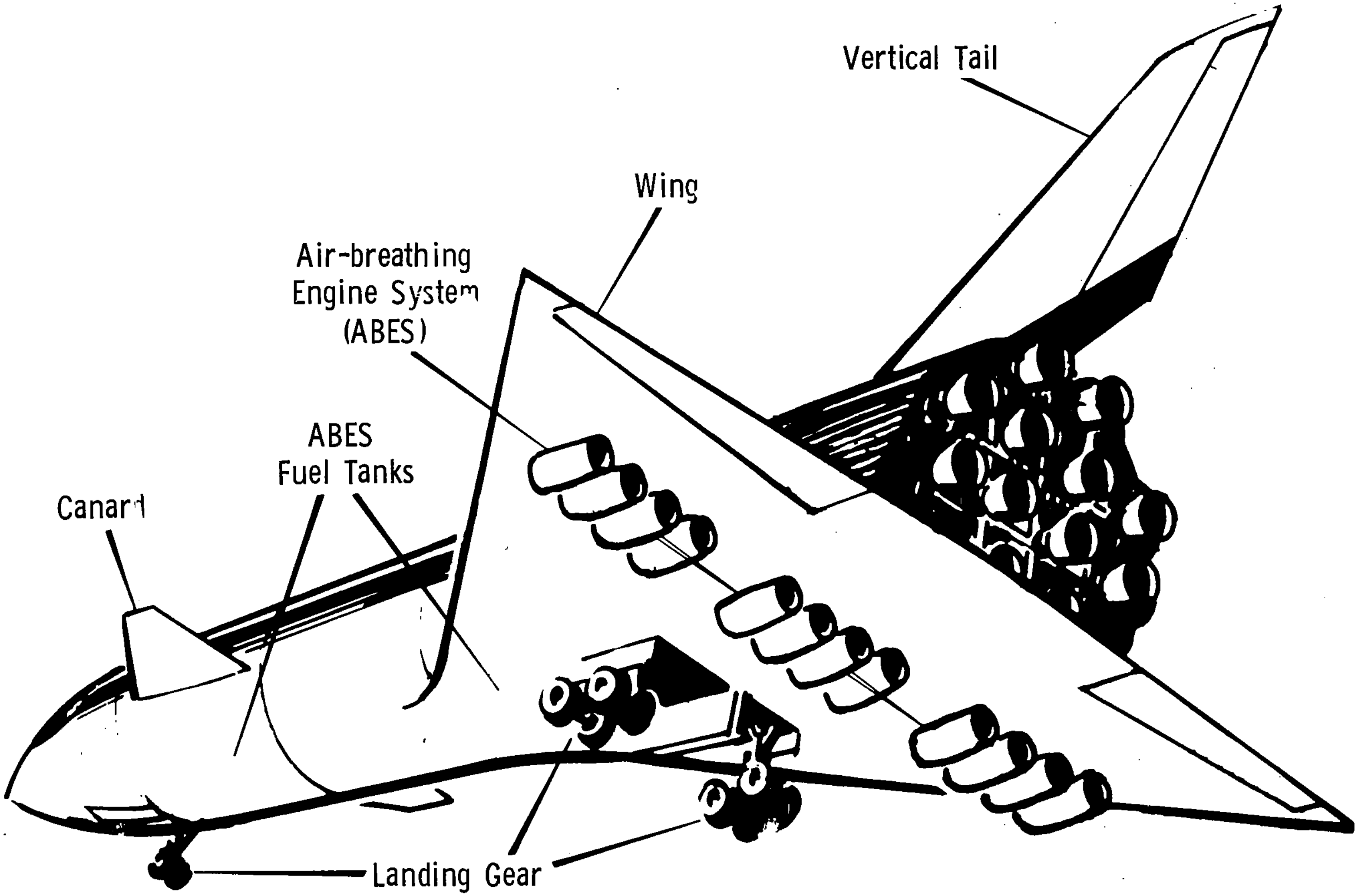


Figure 2

PROBLEM VARIABLES, PARAMETERS, AND OPTIONS

(Figure 3)

The basic synthesis problem is configuration definition corresponding to minimum fly-back system weight or cost or some combination of weight and cost - which in turn tends to minimize the total cost of the overall space transportation system. In addition, there are related problems involving sizing (e.g., in response to changes in payload requirements); sensitivities (e.g., required weight with respect to air-breathing propulsion specific fuel consumption); various trades and special studies (e.g., cost effectiveness and risk studies); and flight mechanics/performance/mission analysis studies (for fixed vehicles).

The opposing figure presents the independent configuration variables which were selected to be varied arbitrarily in the process of configuration optimization. In addition, canard area, vertical tail area, and fore-and-aft wing location were designated configuration variables but are defined by stability and control requirements, rather than available for arbitrary variation.

The figure also lists some of the configuration parameters and options which were selected to accommodate the treatment of various types of designs. Some of the flight mechanics/performance/mission analysis options which were selected to permit handling of essentially all types of situations in this area are also given.

PROBLEM VARIABLES, PARAMETERS, & OPTIONS

- INDEPENDENT CONFIGURATION VARIABLES
  - WING
    - Area (S) or Wing Loading (W/S)
    - Sweep (Λ)
    - Aspect Ratio (AR)
    - Thickness Ratio (t/c)
    - Taper Ratio (λ)
  - AIR-BREATHING ENGINE
    - Thrust Level (ϵ) or Thrust-to-Weight (T/W)
    - Number (N)
- OTHER CONFIGURATION VARIABLES
  - CANARD AREA
  - VERTICAL TAIL AREA
  - WING LOCATION
- CONFIGURATION PARAMETERS & OPTIONS
  - AIR-BREATHING ENGINE LOCATIONS
  - FUEL TANK LOCATIONS
  - LANDING GEAR LOCATIONS
  - WING-LOCATION CRITERIA AND LIMITS
  - VERTICAL TAIL CRITERIA
  - AND OTHERS
- FLIGHT MECHANICS/PERFORMANCE/ MISSION ANALYSIS OPTIONS
  - ENTRY FLIGHT PATH
  - CRUISE RULES
  - LANDING AND TAKEOFF RULES
  - ATMOSPHERE
  - WINDS
  - AND OTHERS

Figure 3

OVERALL APPROACH

(Figure 4)

The need to consider a large number of configuration variations, coupled with the complexity of this system, makes a computerized synthesis approach very desirable, if not mandatory. In response to this need, a booster flyback system synthesis computer procedure has been developed.

The two basic types of synthesis tasks which are accommodated by this procedure are (1) sizing (scaling a fixed-shape configuration in response to changes in mission/payload requirements, structural weight estimates, etc.); and (2) synthesis per se, involving changes in both size and shape (e.g., wing sweep, wing thickness ratio, engine thrust level, etc.). In addition, the procedure can be used to evaluate the flight mechanics/performance mission analysis capabilities and characteristics of fixed-configuration vehicles.

The overall approach to the booster flyback system synthesis computer procedure is summarized in the figure.

An arbitrary configuration is set by specification of (1) the independent configuration variables for the flyback system and (2) fixed booster body. The procedure then locates the wing in a fore-and-aft direction, and sizes the canard and vertical tail - on the basis of stability and control considerations. At this point, the configuration is completely specified, and the force-type data (aerodynamic forces, air-breathing propulsion data, and mass properties) are determined. The performance of the vehicle is then evaluated through the entry and cruise-back phases of the mission, with aerodynamic heating computations being carried out during entry. The cruise-back capability of the booster is compared with the range to the desired landing site at the end of entry, and if it does not agree, a new fuel weight is estimated by the procedure. This requires recomputation of the structural weights and stability and control considerations.

When the landing-location (or range) criterion is satisfied in this weight-sizing iteration, additional performance is computed as desired.

OVERALL APPROACH

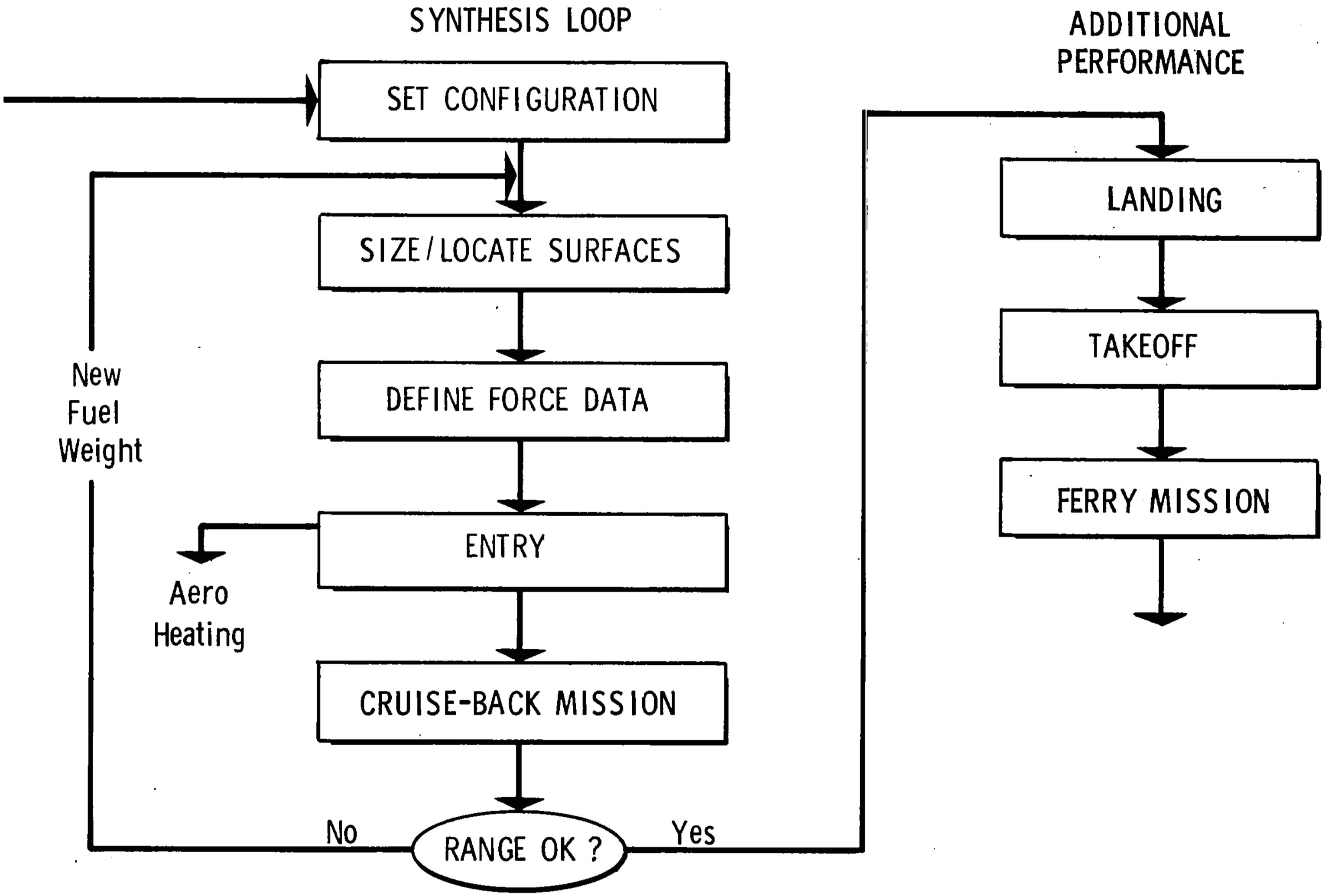


Figure 4

PROGRAM MODULES

(Figure 5)

As indicated in the figure, the procedure is concerned with two primary functions, technology data generation and flight mechanics/performance evaluation, and two secondary functions, geometry and procedure control. These are considered secondary from the standpoint of computational complexity.

The technology considerations which are involved in this problem cover all of the basic technology areas and all flight regimes. In addition, the complex interactions resulting from these technology considerations, superimposed on the flight mechanics/performance framework of the flyback mission, result in a very involved configuration synthesis process.

The following figures summarize each of the five technology areas, flight mechanics/performance, and geometry. Procedure control is not discussed per se, but is implied in the other discussions.

PROGRAM MODULES

- TECHNOLOGY DATA
  - Aerodynamic Forces
  - Air-Breathing Propulsion
  - Mass Properties
  - Stability & Control
  - Aerodynamic Heating
- FLIGHT MECHANICS/PERFORMANCE
  - Entry
  - Cruise-Back
  - Landing
  - Takeoff
  - (Ferry)
  - (Abort)
- GEOMETRY
- CONTROL

Figure 5

THE REFERENCE CONFIGURATION METHOD

(Figure 6)

The key element of a configuration synthesis computer procedure is the technology data generation function. The overall usefulness of the procedure is largely determined by how well this function is conceived and implemented.

The figure summarizes the technology data approach which is used. It is particularly well suited to the handling of synthesis studies for vehicles which are at a stage of their development such that they are receiving intensive treatment by the various functional areas of the engineering organization (e.g., aerodynamic analyses and wind tunnel tests, design layouts, stability and control evaluations, etc.). Provision is made for storing a reference configuration definition (usually the current baseline design) and its corresponding technology data (aerodynamic force data, propulsion data, etc.). In addition, provision is made for storing technology perturbation data (e.g., lift and drag variations as functions of the independent configuration variables).

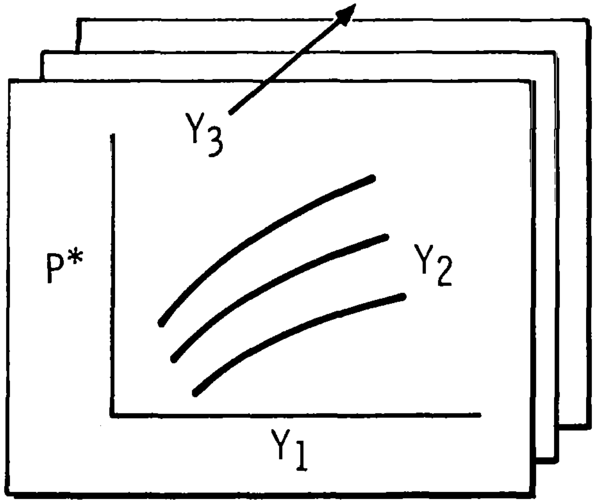
When values of the independent configuration variables are specified which differ from the stored reference set, the technology data are determined by perturbing off of the stored set of reference configuration data, thus forcing the synthesis procedure to agree with the detailed external evaluation provided for the reference (baseline) configuration. In the figure, the Y's represent mission and operation-type variables, (e.g., Mach number, angle of attack, flap position. The X's represent the independent configuration variables (e.g., aspect ratio, sweep). An asterisk denotes reference conditions, and a tilde denotes perturbation data.

The reference configuration library can be changed whenever it is thought to be necessary (e.g., following a baseline configuration change or a wind tunnel test). Similarly, the perturbation libraries (e.g., mass properties) can be changed as is deemed appropriate, (although this will probably not be necessary with every reference library change). It is important to emphasize that the reference and perturbation library data are generated external to and independent of the synthesis procedure using whatever level of detail is available and appropriate (analysis and/or test data of any origin).

REFERENCE CONFIGURATION METHOD

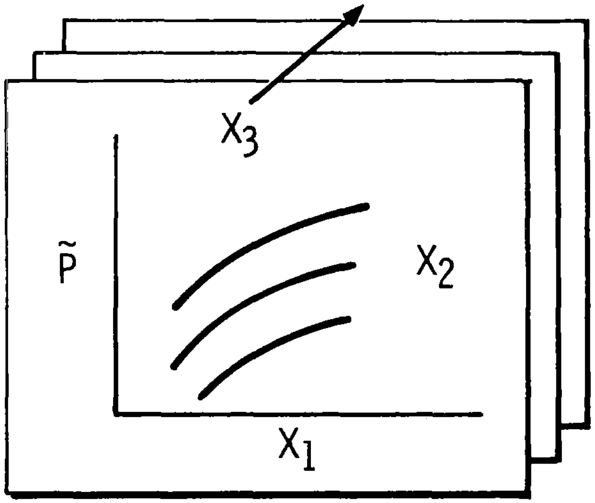
REFERENCE DATA:

- Externally Generated, Internally Stored Configuration and Data as Functions of Flight Variables



PERTURBATION DATA:

- Externally Generated, Internally Stored Data as Functions of Configuration Variables



$$P(X, Y) = P^*(Y) + \overbrace{\left[\tilde{P}(X, Y) - \tilde{P}(X^*, Y)\right]}^{\Delta P}$$

Data for Current Configuration	Reference Configuration Data	Perturbation Data for Current Configuration	Perturbation Data for Reference Configuration

Figure 6

TECHNOLOGY FUNCTIONS AND METHODS

(Figure 7)

The opposing figure indicates (1) the type of data provided by each of the five technology areas, and (2) the computational approach used in each area.

TECHNOLOGY FUNCTIONS and METHODS

	PROVIDES	THROUGH
● AERODYNAMIC FORCES	Lift and Drag	Reference Configuration + Size and Shape Perturbation Data
● MASS PROPERTIES	Weight and C.G. Data	
● STABILITY AND CONTROL	Surface Location and Sizing	
● AIR-BREATHING PROPULSION	Thrust and Fuel Flow	Scaling of Reference Engine Data
● AERODYNAMIC HEATING	Heating Data (Information Only)	Several Analytical Models

Figure 7

AERODYNAMIC FORCES

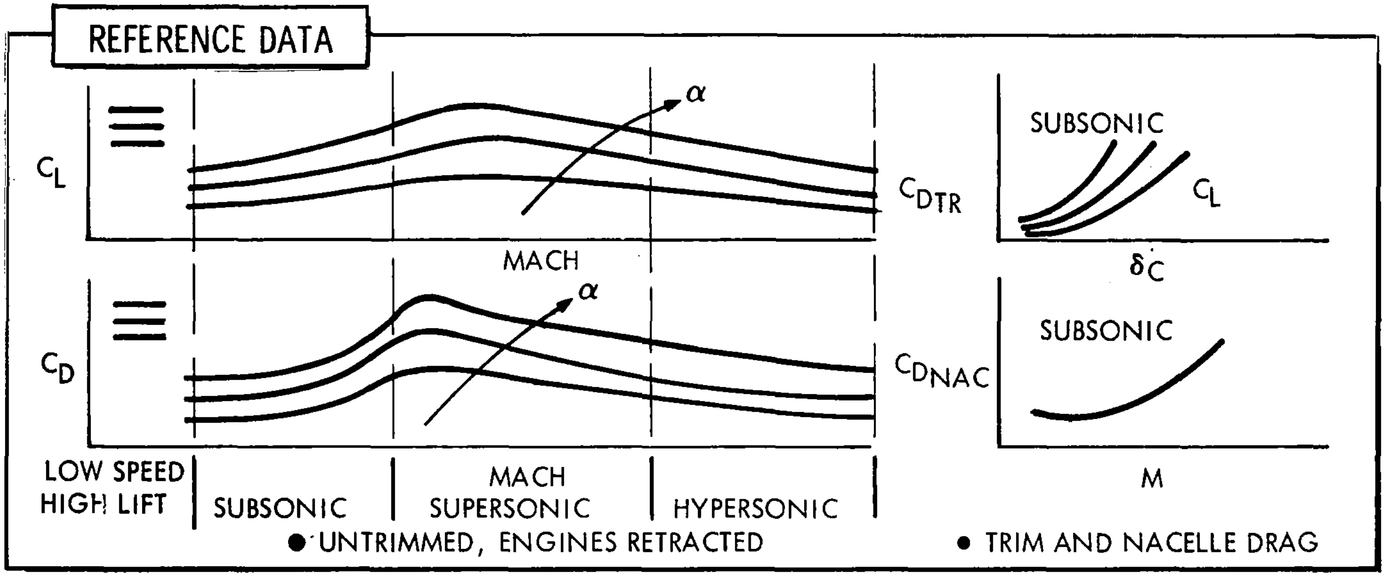
(Figure 8(a))

The opposing figure presents the approach used in the procedure for generating lift and drag data of an arbitrary fly-back system configuration definition. As shown in the upper part of the figure, reference lift and drag data are stored in the aerodynamic forces portion of the reference configuration library. Note the provision for separate low speed/high lift data and for engine stowage and dèployment in terms of nacelle drag. Drag increments are also provided for gear deployment, drag chute deployment, etc. Perturbation data, of the type shown in the lower part of the figure, are used to perturb the reference lift and drag data when a configuration which differs from the reference configuration is called for.

For example, an aspect ratio of 3.0 is specified when the reference configuration aspect ratio is 2.5. In this case, the perturbation data account for all the changes in the reference data due to a change only in aspect ratio. If several configuration variables (e.g., aspect ratio, sweep, and engine thrust level) were specified different from their reference configuration values, then lift and drag perturbation data corresponding to the combined effect would be generated. Note the provision for different sets of lift and drag increments for each flow regime: low speed/high lift, subsonic, supersonic, and hypersonic.

The basis of the perturbation process for the aerodynamic data is the use of a linear lift curve and a parabolic drag polar. The parameters which define these familiar representations (α_{LO}, C_{L_α}, ΔC_L, $C_{D_{MIN}}$, K, etc.) are externally-generated data which are stored in the aerodynamic forces perturbation library. As is indicated in the figure, the parameters are stored as functions of (1) the independent configuration variables and (2) other configuration variables (e.g., canard area). In addition to the configuration variables (which are underlined in the figure), some other internally-generated variables also appear (e.g., C_{L_α}, e, etc.). The double asterisks denote subsonic data which are also used for low speed/high lift.

AERODYNAMIC FORCES



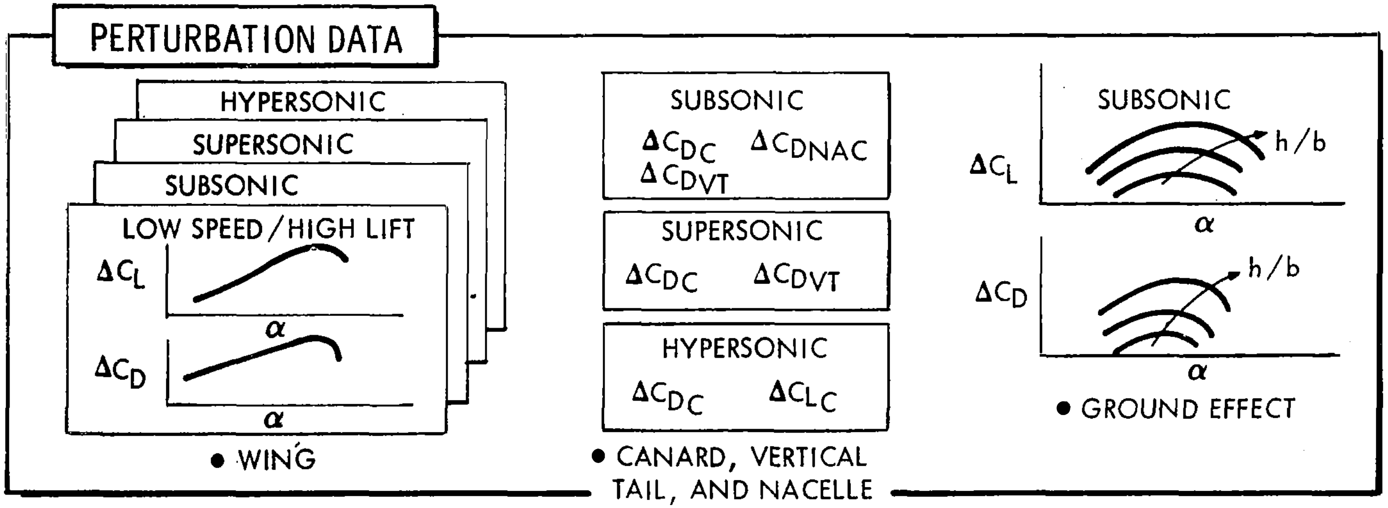


Figure 8(a)

AERODYNAMIC FORCES (Cont'd)

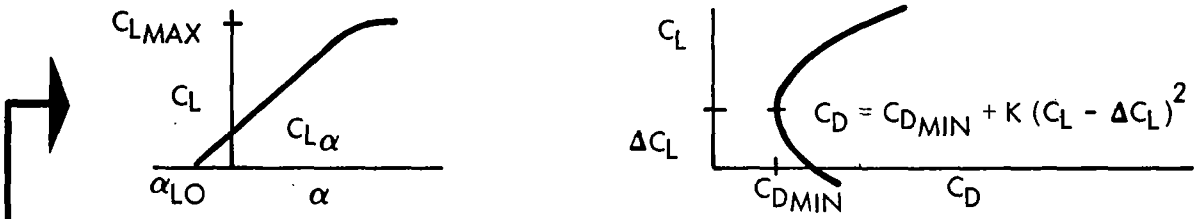
(Figure 8(b))

The process of generating the type of perturbation data shown in the lower part of the previous figure is as follows. The lift curves and polars are entered first at reference configuration conditions and then at perturbation conditions. The lift and drag differences between these two entries provide the perturbation increments which are then applied to the reference data to define the lift and drag characteristics of the new configuration.

It should be pointed out that the procedure assumes a linear lift curve and a parabolic drag polar only in the process of determining the perturbation data. The reference data are dependent on no such assumption. Furthermore, separate sets of lift curve and polar parameters are used for each speed regime.

AERODYNAMIC FORCES

- FUNCTIONAL DEPENDENCIES OF PERTURBATION DATA



REGIME	WING	CANARD	VERTICAL TAIL	NACELLE
LOW SPEED / HIGH LIFT (Landing and Takeoff)	$C_{L_O}(\underline{AR}, C_{L_\alpha})$ $C_{L_{MAX}}(\underline{AR}, \underline{\Lambda}, \underline{\lambda})$ $\Delta C_L(C_{L_\alpha}, C_{L_O}, e)$ $C_{D_{FLAP}}(\underline{AR}, \underline{\Lambda}, \underline{a})$ $\Delta\alpha(h/b, \underline{AR}, C_L)$ α^*_{PB} e^*_{MAX}	$C_{D_C}(\underline{S_C})$	$C_{D_{VT}}(\underline{S_{VT}})$	$C_{D_{NAC}}(\underline{S_{NAC_{WET}}})$
SUBSONIC (Cruise)	$^{**}C_{D_{MIN}}(\underline{S}, \underline{\Lambda}, \underline{t/c})$ $^{**}C_{L_\alpha}(\underline{AR}, \underline{\Lambda}, \underline{a}, \underline{\lambda})$ $\alpha_{LO}(\underline{AR}, \underline{\Lambda}, \underline{\lambda})$ $^{**}K(C_{L_\alpha}, \underline{AR})$ $\Delta C_L(\underline{AR}, K)$			
SUPERSONIC (Entry and Transition)				—
HYPERSONIC (Entry)	$C_L(\underline{S}, \alpha)$ $C_D(\underline{S}, \alpha)$	$C_{D_C}(\underline{S_C})$ $C_{L_C}(\underline{S_C})$	—	—

Figure 8(b)

MASS PROPERTIES

(Figure 9)

As summarized in the figure, the procedure accounts for both weight changes and longitudinal center of gravity changes as functions of the configuration variables. The general approach is the same as that employed for the aerodynamic forces. However, since the component weights are not functions of the mission variables (i.e., Mach number and angle of attack), the mass properties portion of the procedure is considerably less complex.

Reference weights and centers of gravity of the fly-back system components listed in the figure are stored in the mass properties portion of the reference configuration library. Parametric weight increments for the components listed in the figure are obtained by entering the parametric weight libraries twice (once with the reference values and once with the perturbed values of the configuration variables). Weight increments for other flyback system components are computed analytically (e.g., ABES tank weight as a function of ABES fuel weight). All vehicle components not included in the flyback system are included in a fixed body weight. A contingency weight may be computed internally from an analytical expression.

Longitudinal center of gravity perturbations are handled analytically (e.g., wing c.g. is assumed to move as a constant percentage of the mean aerodynamic cord as the wing planform changes).

MASS PROPERTIES

- WEIGHTS

- REFERENCE WEIGHTS FOR
  - Wing
  - Canard
  - Vertical Tail
  - Propulsion (ABES)
    - √Engine
    - √Nacelle
  - Gear
    - √Nose
    - √Main

PLUS

- Parametric Weight Increments for Flyback System Components
- Fixed Body Weight
- Contingency Weight

- Dry Fly-Back System (FBS) Weight + ABES Fuel
- Total FBS Weight

- LONGITUDINAL C.G.'s

  Reference Values + Analytical Variations = Total C.G.

Figure 9

STABILITY AND CONTROL

(Figure 10)

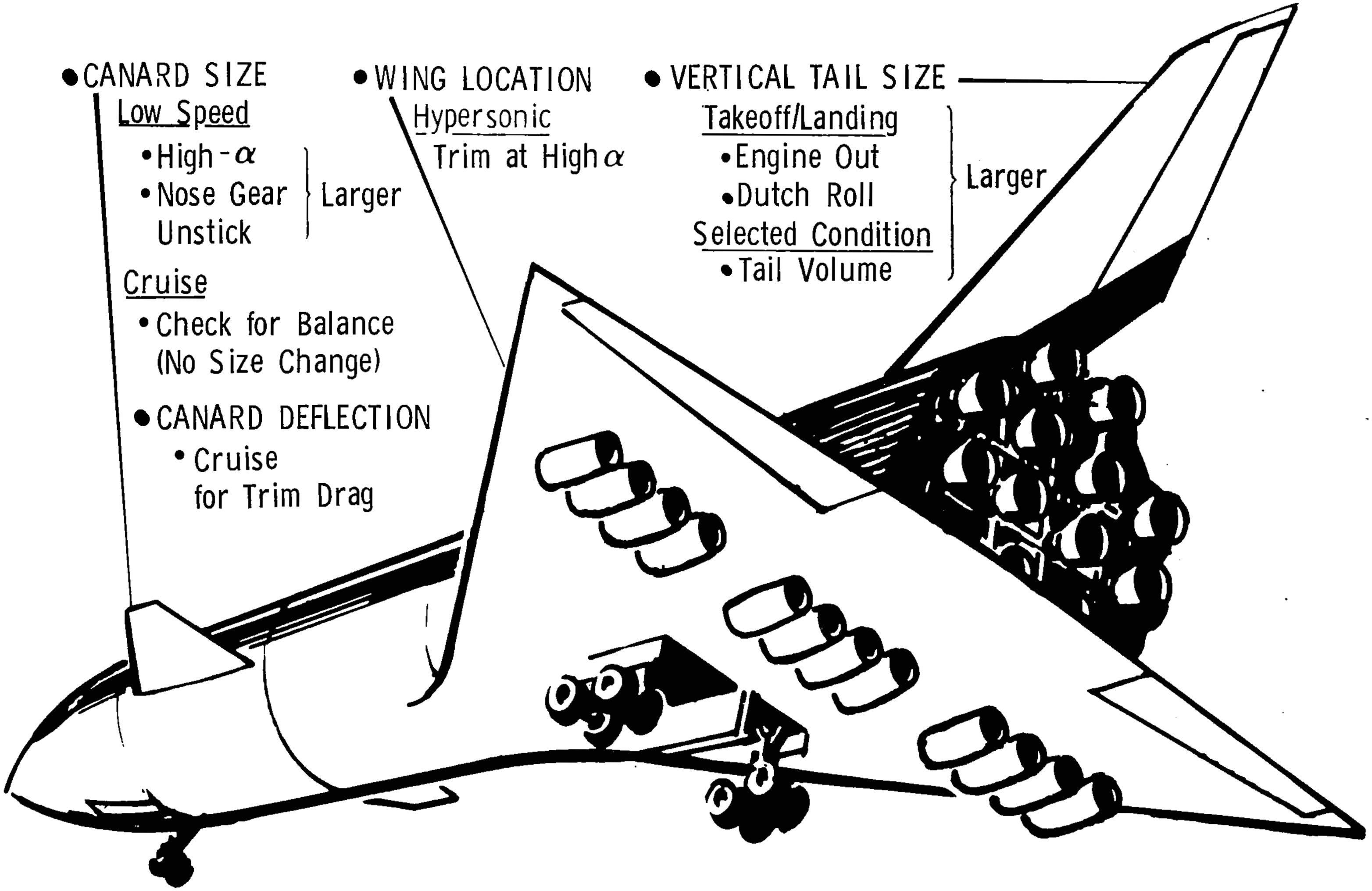
The stability and control functions are (1) to locate the wing fore-and-aft (wing size is an independent variable); (2) to size the canard (location is specified for a given reference configuration), and (3) to size the vertical tail (location is specified).

It should be noted that cruise balance can not be assured for an arbitrary configuration definition. The reason for this is that a minimum size canard is selected on the basis low-speed trim requirements, and this minimum size may be larger than the maximum size which is consistent with a desired positive static margin. In such a case, some other configuration change could be considered - e.g., wing size, fuel location (center of gravity, etc.).

Canard deflection during cruise and approach is determined for use in determining trim drag. In the overall synthesis process, the wing location affects the required canard size, and the resultant canard and vertical tail sizes affect the aerodynamic forces and the total weight.

The stability and control computations use reference values of aerodynamic forces and moments and other parameters, and perturbations off of these reference values. Both externally-generated, internally-stored data and analytical relationships are used.

STABILITY and CONTROL



- CANARD SIZE
  - Low Speed
    - High-α
    - Nose Gear Unstick
    - Larger
  - Cruise
    - Check for Balance (No Size Change)
- CANARD DEFLECTION
  - Cruise for Trim Drag
- WING LOCATION
  - Hypersonic
    - Trim at High α
- VERTICAL TAIL SIZE
  - Takeoff/Landing
    - Engine Out
    - Dutch Roll
  - Selected Condition
    - Tail Volume
  - Larger

Figure 10

AIR-BREATHING PROPULSION

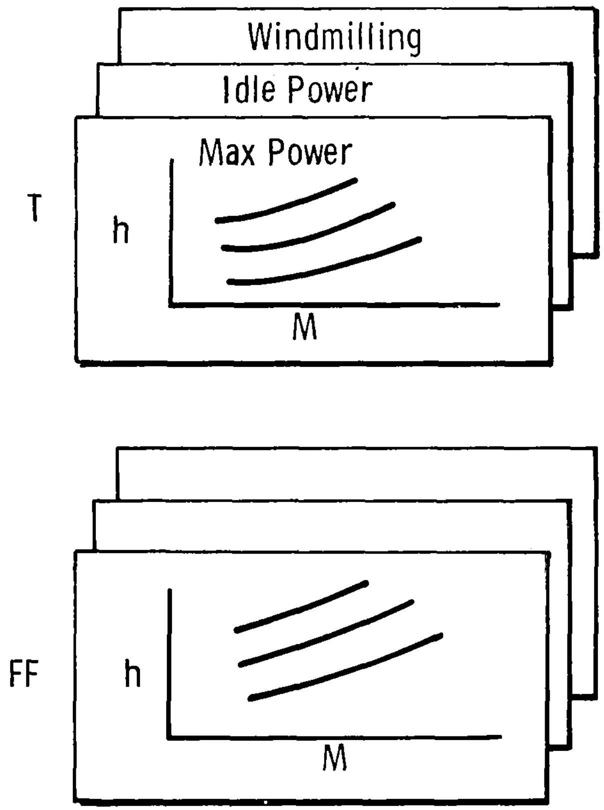
(Figure 11)

Unlike the wing, which is permitted to change in both size and shape, the air-breathing engines are of fixed design (for a given reference configuration) and are only scaled up and down in size. The reference engine thrust and fuel flow data are stored in the propulsion library as functions of altitude and Mach number. The independent engine configuration variable is ϵ , the ratio of perturbed engine thrust level to reference engine thrust level. As shown in the figure, thrust and fuel flow for scaled engines (primed values) are obtained by multiplying the reference values by the scale factor ϵ . The scaling is performed under the assumption of constant specific fuel consumption. Nacelle diameter and length changes are computed on the basis of the expressions shown in the figure, where k can be either constant or a function of ϵ .

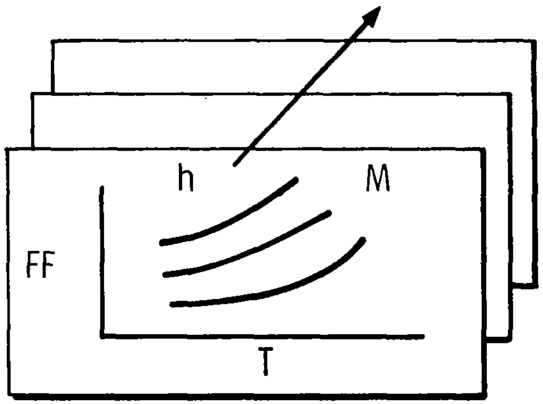
AIR-BREATHING PROPULSION

THRUST SCALING OF A FIXED CONFIGURATION

- FIXED POWER DATA



- THRUST/FUEL FLOW DATA



- SCALING RELATIONS

$T' = T \cdot \epsilon$

$FF' = FF \cdot \epsilon$

$D' = D\epsilon^{1/2}$

$L' = L\epsilon^{k}$

} Engine Geometry

Figure 11

AERODYNAMIC HEATING

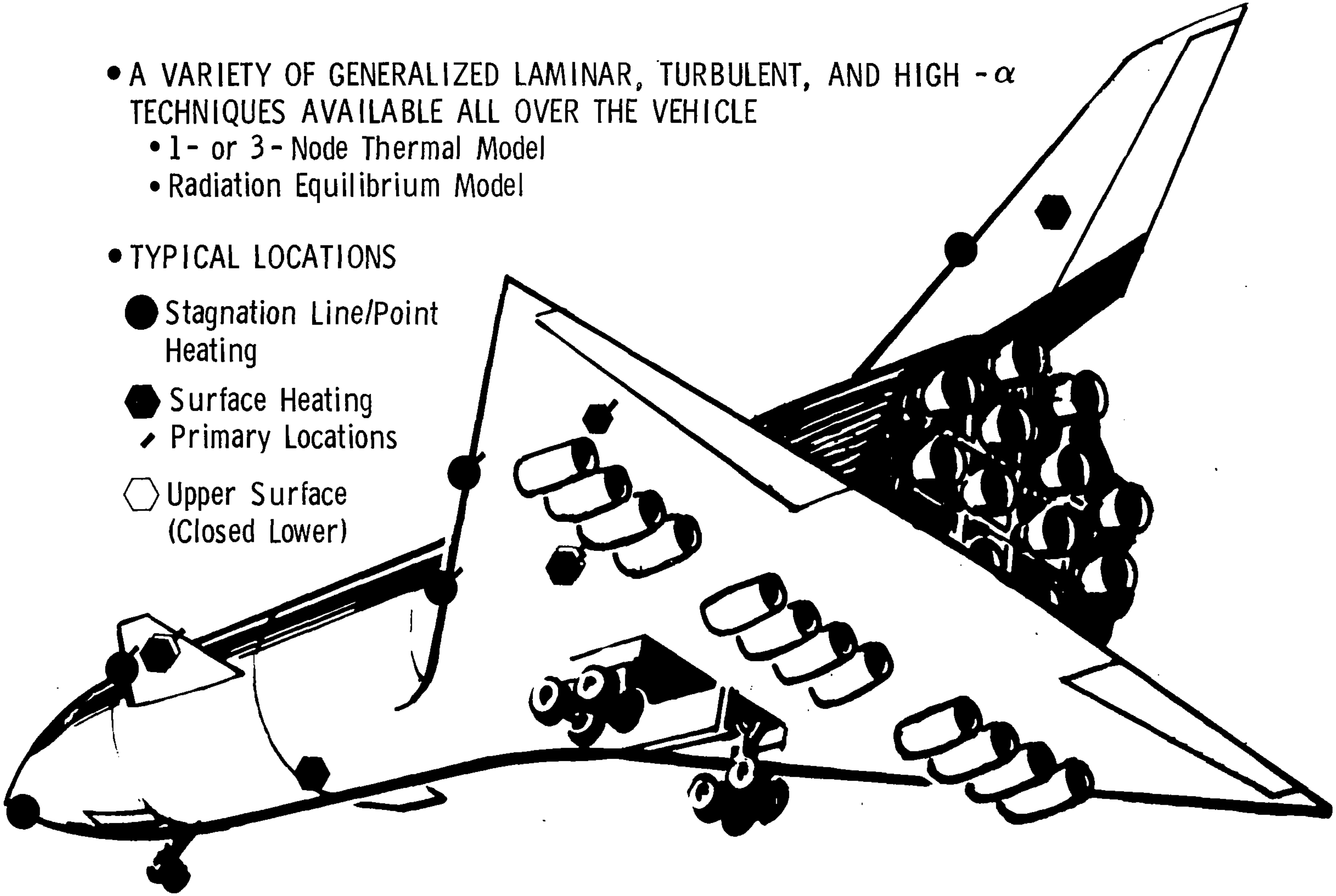
(Figure 12)

Changes in maximum temperatures and heating rates affect the synthesis process directly by influencing weight requirements. In addition, heating data provide guidance for materials selection; structural concept formulation (e.g., heat sink, hot structure, etc.); and general design (e.g., canard location to avoid severe shock-impingement heating). The heating/weight interaction could have been handled internally by making the weight perturbation data a function of the aerodynamic heating parameters. However, for simplicity, it was elected to treat this interaction external to the procedure. Therefore, the aerodynamic heating data are generated for information only and are used externally to (1) verify, or modify if necessary, the reference configuration weights and weight perturbation data, and (2) to provide design guidance.

A variety of generalized laminar, turbulent, and high angle of attack techniques are available to compute temperatures and heating rates at up to twelve locations over the vehicle. The appropriate method is selected internally by the program based on input switching values of Reynold's Number and angle of attack. Either a three-node or a one-node model may be specified at a given location. A radiation equilibrium calculation can be included in each model.

A typical problem may include (1) stagnation heating computations at selected points on the surface leading edges and on the nose, (2) surface heating computations at representative points on the body, wing and tail, and (3) surface heating of the upper and lower surfaces at given locations on the wing and canard using a three-node model.

AERODYNAMIC HEATING



- A VARIETY OF GENERALIZED LAMINAR, TURBULENT, AND HIGH -α TECHNIQUES AVAILABLE ALL OVER THE VEHICLE
  - 1- or 3-Node Thermal Model
  - Radiation Equilibrium Model

- TYPICAL LOCATIONS

● Stagnation Line/Point Heating

⬢ Surface Heating
/ Primary Locations

⬡ Upper Surface (Closed Lower)

Figure 12

FLIGHT MECHANICS/PERFORMANCE/MISSION ANALYSIS

(Figure 13)

During each pass through the weight-sizing loop, the flyback capability of the vehicle is determined by integration of the path from landing back to the beginning of cruise. The required flyback range is determined by integration of the entry path from staging to engine deployment.

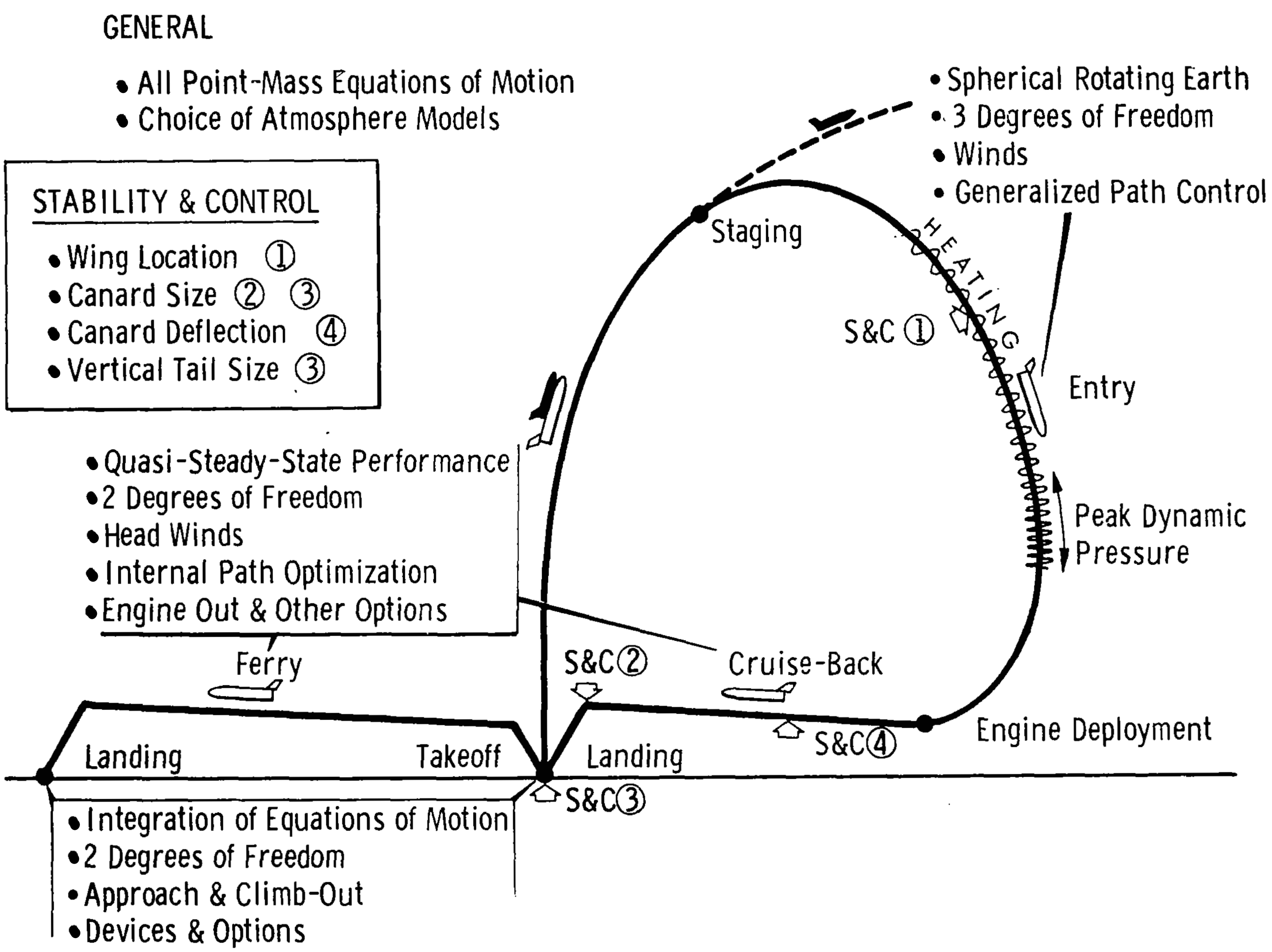
The entry path is integrated with a three-translational-degree-of-freedom procedure developed on another project. It assumes a spherical, rotating earth and a wind profile that varies in speed and direction with altitude. The procedure includes a set of transformations which allow the type of entry path to be specified as a series of segments with virtually any type of controls.

The cruise routines are based on quasi-steady-state equations of motion in two degrees of freedom. A head-wind profile and various engine-out options are provided. The cruise paths may be internally optimized on altitude and/or speed with ceiling contraints and cruise-climb corrections applied.

An optional descent path at idle power may be integrated if range credit is allowed. Landing reserves are computed from any combination of (1) a fixed fuel allowance, (2) a percentage of total fuel available, and (3) a specified duration at constant altitude and optimum or constant speed.

On the final pass through the sizing iteration, i.e., when the weight at entry satisfies the flyback requirement, the aerodynamic heating equations are integrated during the integration of the entry path. Other performance calculations are also made at this point. These include takeoff and landing simulations to determine runway length requirements and integration of a ferry mission to determine ferry range capability.

FLIGHT MECHANICS/PERFORMANCE/MISSION ANALYSIS



GENERAL

- All Point-Mass Equations of Motion
- Choice of Atmosphere Models

- Spherical Rotating Earth
- 3 Degrees of Freedom
- Winds
- Generalized Path Control

STABILITY & CONTROL

- Wing Location ①
- Canard Size ② ③
- Canard Deflection ④
- Vertical Tail Size ③

- Quasi-Steady-State Performance
- 2 Degrees of Freedom
- Head Winds
- Internal Path Optimization
- Engine Out & Other Options

- Integration of Equations of Motion
- 2 Degrees of Freedom
- Approach & Climb-Out
- Devices & Options

Figure 13

EXAMPLE GEOMETRY VARIABLES - PLANFORM

(Figure 14)

Numerous geometrical variables must be determined for use in the various technology computations (e.g., reference areas for aerodynamic forces, moment arms for stability and control, etc.) and in the computer graphics routines. Some of the planform variables involved in this process are illustrated in the figure. For example, secondary wing planform variables such as exposed and theoretical root chords, tip chord, exposed mean aerodynamic chord, etc., are computed from primary configuration variables such as exposed wing area, leading edge sweep, aspect ratio, and taper ratio.

Numerous options are available to accommodate a wide variety of configuration types. These options relate to such things as the locations of engines, cruise fuel tanks, and main landing gear and how each moves as the primary configuration variables are perturbed.

EXAMPLE GEOMETRY VARIABLES - PLANFORM

WING:

- Area - S_{Exp}
- Sweep - Λ
- Aspect Ratio - $AR = b^2/S$
- Thickness Ratio - t/c
- Taper Ratio - $\lambda = C_T/C_{R\,Exp}$

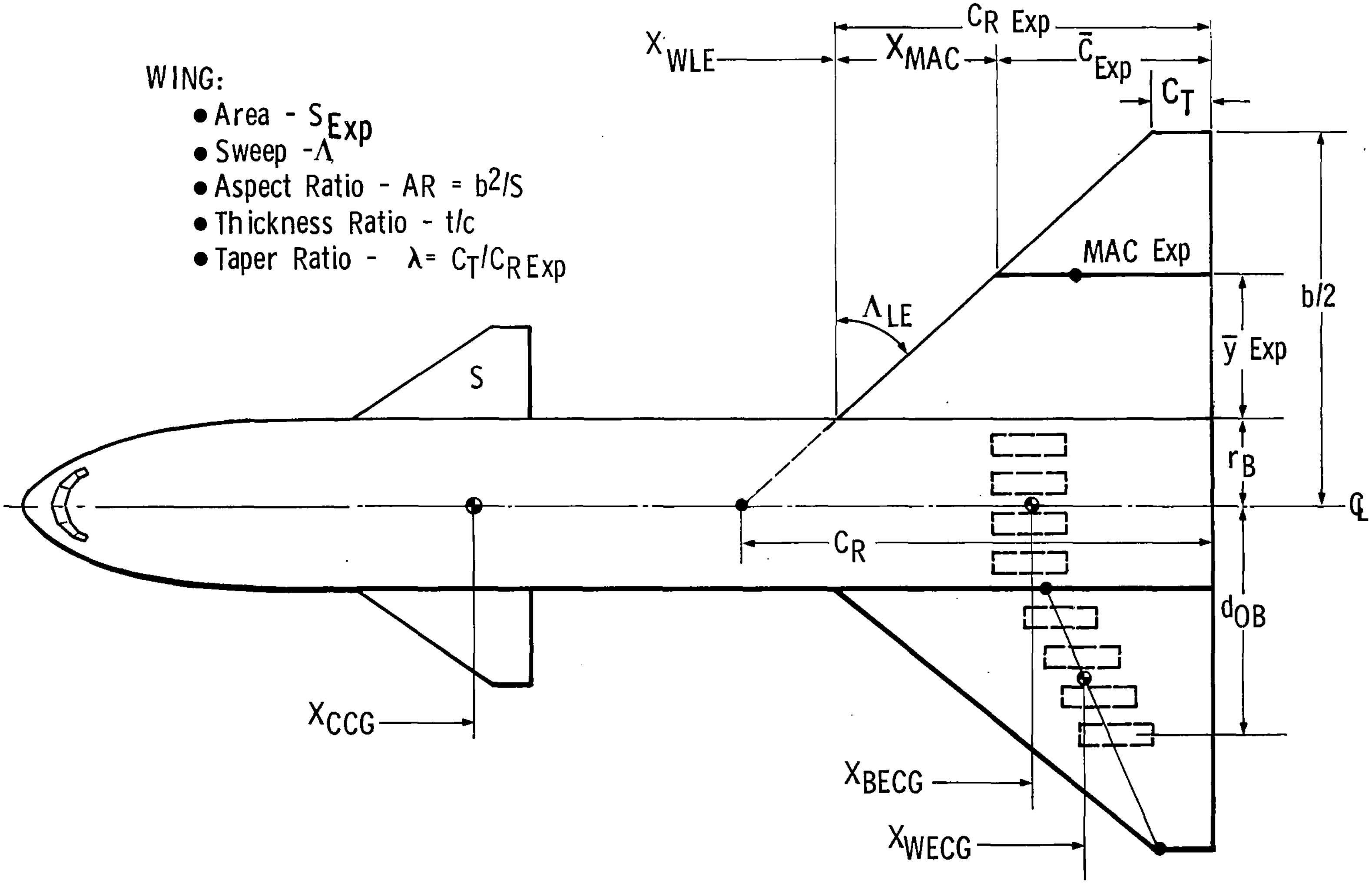


Figure 14

EXAMPLE GEOMETRY VARIABLES - PROFILE

(Figure 15)

In addition to the planform variables mentioned on the previous page, other geometry variables pertaining to the vehicle profile are computed. For example, ground interference angles for wing trailing edge root and tip chords and vehicle tail bump are computed for the purpose of determining the maximum pitch angle. Another example is the location and orientation of the resultant thrust vector with respect to the vehicle center of gravity which is provided for use in stability and control computations.

EXAMPLE GEOMETRY VARIABLES - PROFILE

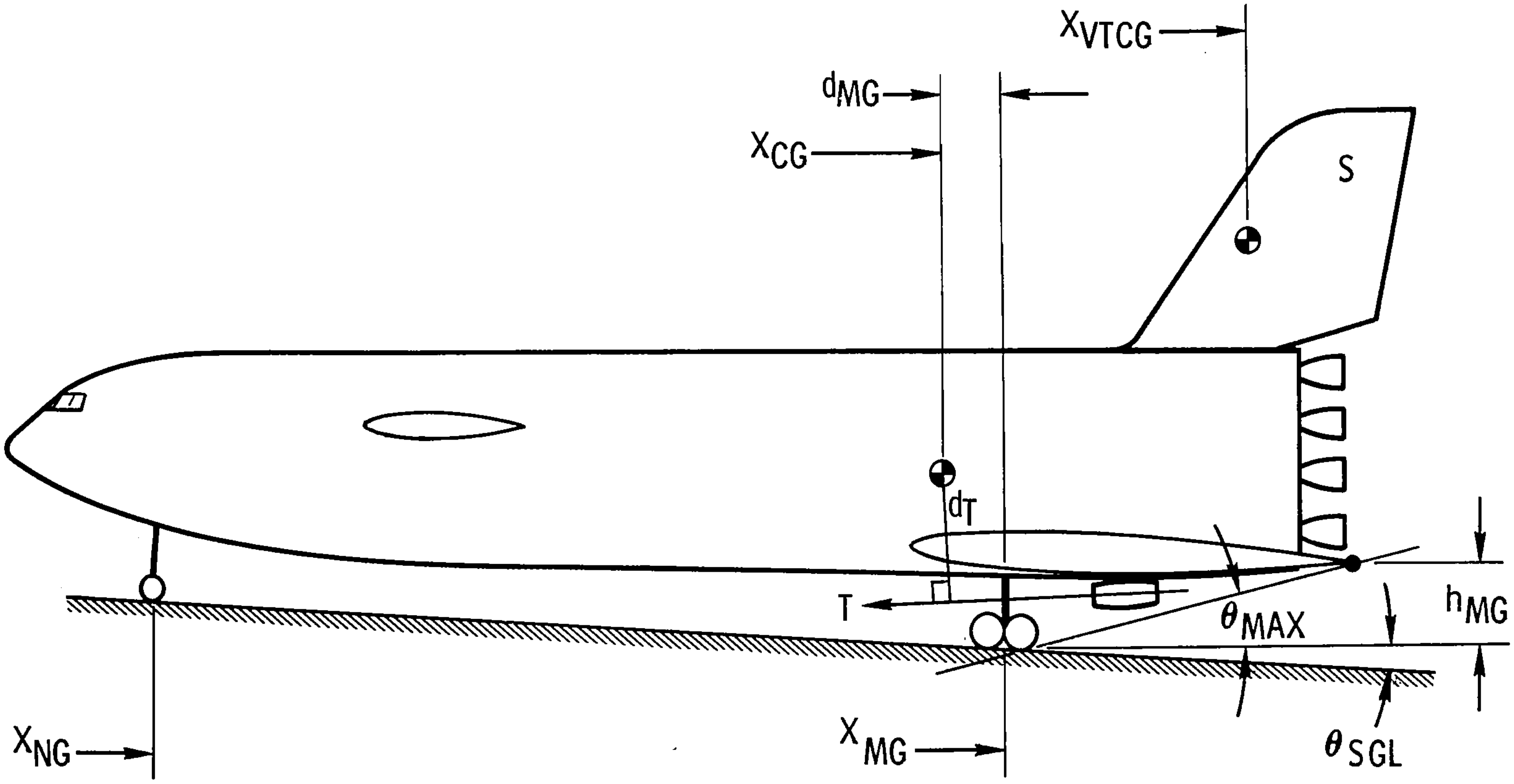


Figure 15

PROGRAM APPLICATIONS
(Figure 16)

The computer procedure which has been developed is designed to treat a number of different types of problems associated with configuration definition and evaluation for the booster flyback system of a reusable earth-to-orbit space transportation system.

The figure summarizes the principal areas of procedure application and the basis of its operation. For specified configurations, the procedure can be used simply as a flight mechanics/performance/aerodynamic-heating evaluation tool of considerable detail and versatility. However, its most powerful utilization is (1) to scale an existing configuration up or down (e.g., to accommodate a different payload weight); or (2) to synthesize a completely new configuration - to the point of optimizing it (e.g., minimum weight). In addition, the procedure can be applied to a number of special problems, including the generation of sensitivity data of all types. For all of these applications, constraints are applied to insure that the proper landing location is achieved and that stability and control criteria are met.

Surveys can be conducted on the seven independent configuration variables shown in the figure. For each point on the parametric curves the program provides a complete set of configuration and flight path definitions with geometry, aerodynamic, stability and control, aeroheating, mass properties and performance summaries.

The results of studies using this procedure will be integrated into overall booster studies, and ultimately into total system (booster plus orbiter) studies.

PROGRAM APPLICATIONS

- FLIGHT MECHANICS/PERFORMANCE/HEATING
- SCALING AN EXISTING CONFIGURATION
- SYNTHESIZING A NEW CONFIGURATION
- CONFIGURATION, MISSION, OTHER SENSITIVITIES
- CONFIGURATION OPTIMIZATION

- SATISFIED CONSTRAINTS
  - Landing Location (Fuel)
  - Trim
- INFORMATION
  - Cruise Balance
  - Aero Heating
  - Landing Performance
  - Takeoff Performance
  - Ferry Performance
  - Etc.

Perturbations on ...

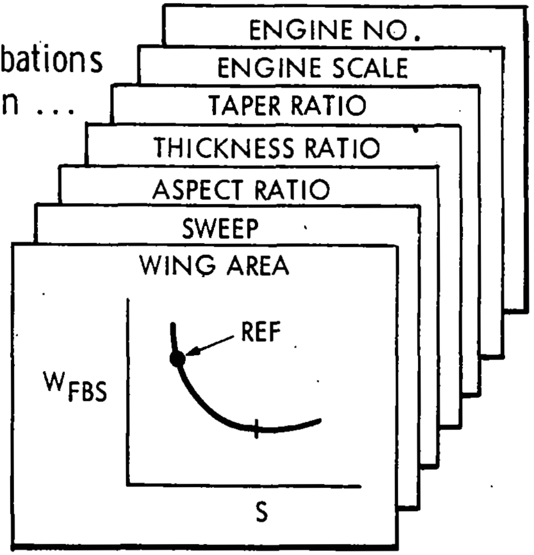


Figure 16

FLIGHT MECHANICS/PERFORMANCE

(Figure 17)

The computer procedure is currently in final checkout and intial operational evaluation. The final three figures present example results which have been obtained in checkout runs. To avoid the impression that these example results imply configuration guidance relative to some real design, several of the variables are plotted in normalized form, rather than as actual values.

The opposing figure presents a typical entry path, starting after staging. A roll program is initiated and a highly pitched, highly banked segment is flown until a load factor limit is reached. The load factor limit is followed by a stability limit specified by a Mach-alpha profile. The turn is continued until the heading to the landing site is achieved.

FLIGHT MECHANICS/PERFORMANCE

- EXAMPLE ENTRY DATA

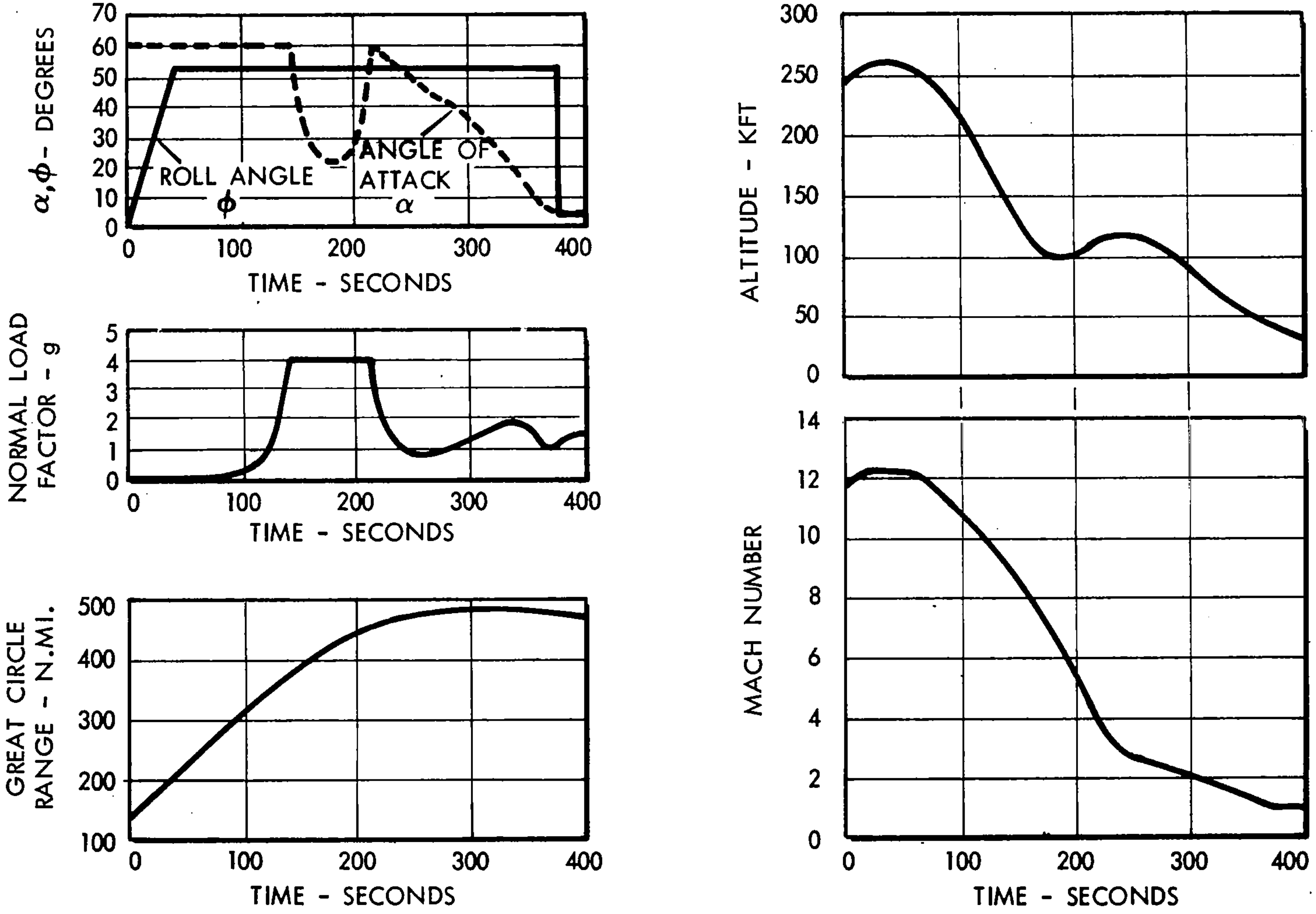


Figure 17

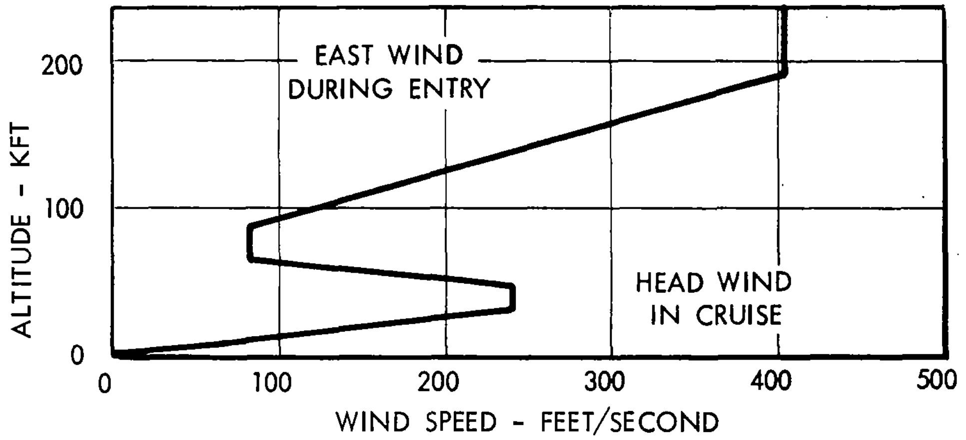
EXAMPLE SENSITIVITY DATA

(Figure 18)

The opposing figure presents the results of sizing two specific configurations with and without an assumed wind profile. This is a severe profile, and it acts essentially as a crosswind during entry and headwind during cruise. The effects of wind on both cruise-back range and flyback system weight are shown.

EXAMPLE SENSITIVITY DATA

- **EFFECT OF WIND**



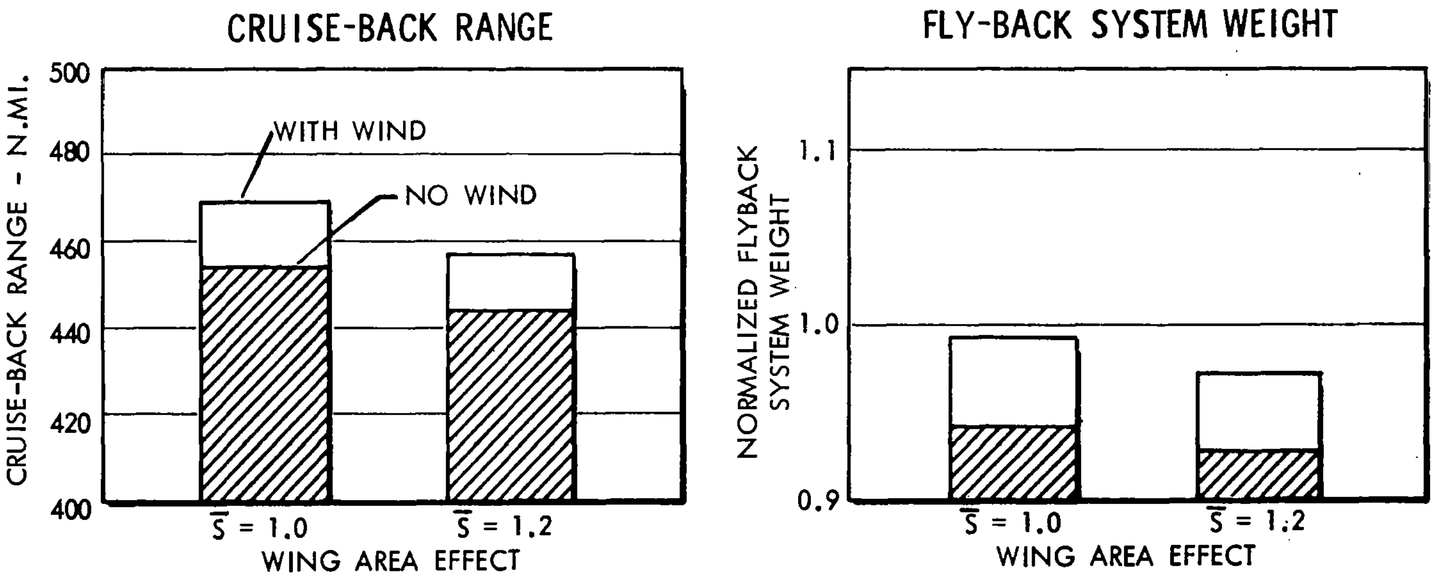


Figure 18

1435

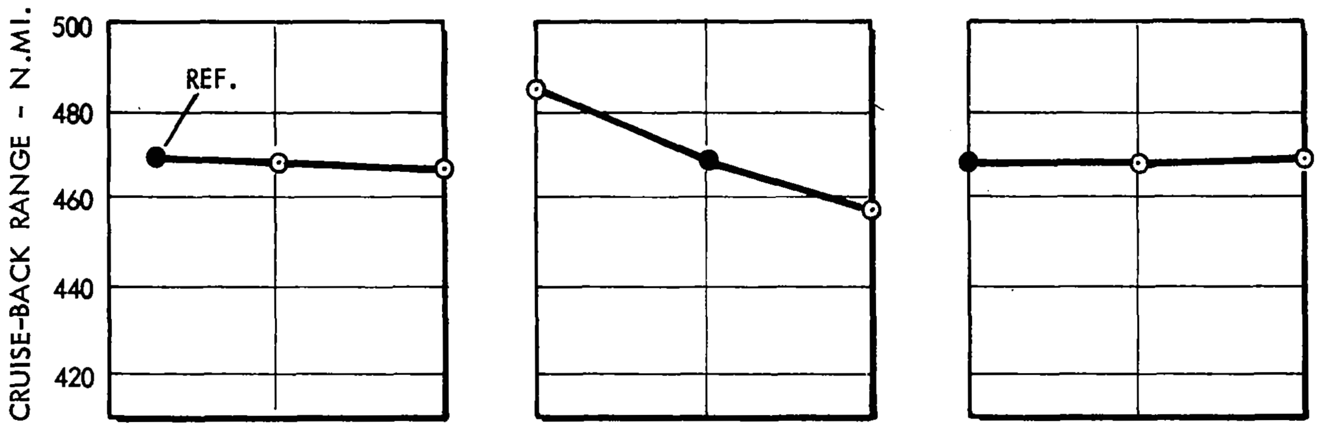
EXAMPLE SYNTHESIS DATA

(Figure 19)

The opposing figure shows the effects on cruise-back range and flyback system weight due to independent variations in aspect ratio, wing area, and engine scale factor. It can be seen that increasing either aspect ratio or wing area decreases flyback system weight. This is due to improved cruise efficiency in the case of aspect ratio, and due to improved deceleration and turning during entry in the case of wing area. The engine scale factor has little effect, because the scaling is done at constant specific fuel consumption.

EXAMPLE SYNTHESIS DATA

- CRUISE-BACK RANGE VARIATIONS



- FLY-BACK SYSTEM WEIGHT VARIATIONS

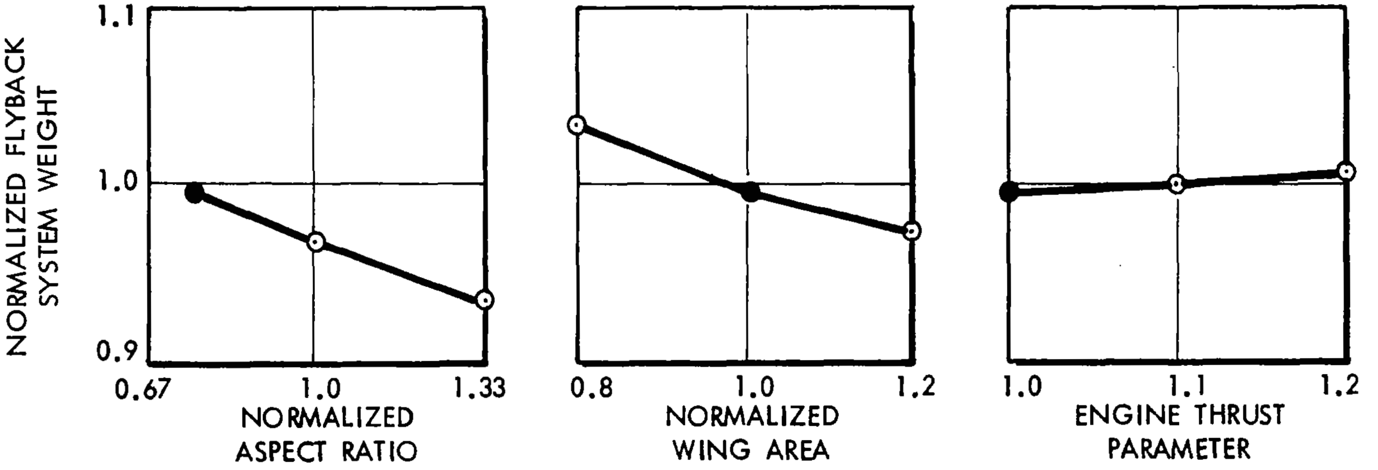


Figure 19