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UNSTEADY AERODYNAMIC CHARACTERIZATION OF
A MILITARY AIRCRAFT IN VERTICAL GUSTS

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16. Abstract The effects of 2.5 m/sec vertical gusts on the flight characteristics of a 1:8.6 scale model of a Mirage 2000 aircraft in free flight at 35 m/sec over a distance of 30 m are investigated. The wind tunnel setup and instrumentation are described; the impulse-response and local-coefficient-identification analysis methods applied are discussed in detail; and the modification and calibration of the gust-detection probes are reviewed. The results are presented in graphs, and good general agreement is obtained between model calculations using the two analysis methods and the experimental measurements.

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TABLE OF CONTENTS

UNSTEADY AERODYNAMIC CHARACTERIZATION OF A MILITARY AIRCRAFT IN VERTICAL GUSTS

A. Le Bozec AMD-BA[1] and J. Cocquerez IMFL[2]

1 - INTRODUCTION

The study of aircraft behavior in atmospheric turbulence generally covers several areas which are significantly interrelated: unsteady aerodynamics, structure dynamics, flying qualities, and piloting.

The impact of turbulence on the flight of a military aircraft is one of the factors limiting operational use; it is essentially linked to pilot fatigue conditions and to a decrease in platform stability.

For the new generation of aircraft equipped with overall automatic control, a direct and optimum action with respect to the effects of turbulence has been sought since these aircraft were conceived.

This process requires that the unsteady aerodynamic effects resulting from turbulence be recognized and modeled in order to have a tool to predict and improve aircraft behavior.

For this report, the IMFL and the AMD-BA, working closely together, have developed experiments to characterize the unsteady aerodynamics of military aircraft in vertical gusts.

These experiments involved an existing model, well defined elsewhere.

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[*]Numbers in the margin indicate pagination in the foreign text.
[1]Research organization, expansion unknown.
[2]Research organization, expansion unknown.

Following a brief review of the experimental method developed to establish a data base, we present the methods of analysis and aerodynamic characterization used, as well as the principal results obtained.

2 - PRINCIPLES AND EXPERIMENTAL METHOD

2.1 - Basic principles - physical similarity

The experiments on a free model are based on the Froude similarity (maintaining the ratio of inertia forces to gravity forces) which allows a similar representation of the trajectory and movement of the aircraft. The variables of the problem are expressed as a function of these primary independent values: gauge length, volumetric mass of the environment, and gravitational acceleration. The principal physical values, their "size," and object-model similarity ratios are presented in Figure 2.

This similarity is limited since, from an aerodynamic point of view, it cannot simultaneously represent the identities of the Reynolds and Mach numbers. We note also that tests on free models relate only to the area of incompressible subsonic flight. In addition, the use of large models makes it possible to reach Reynolds numbers, calculated on the average chord of the blade, in the neighborhood of 2.3×10^6.

The concept of gust response tests is established using an indirect similarity process. The tests on a model constitute experimental support for validating a mathematical model which represents the phenomena. The conditions for the model and for free flights are adapted on a trial-and-error basis.

5

Figure 3 presents a general view of the model used in this work. It is a permeable model of the Mirage 2000 scaled at 1/8.6. The internal and external elevons are interdependent. The nose-tip is kept at 0° during all the experiments. The basic centering is 52%.

The model is instrumented to allow, by means of PCM telemetry, recovery of motion dynamics, recovery of positions and attitudes, and determination of aerodynamic values: local kinetic pressure, incidence, and sideslip via an anemoclinometric probe placed on the furthest forward point and used to measure the gust.

The model's equipment includes (Figure 4):

- 5 accelerometers $\ddot{Z}$ AV, $\ddot{Z}$ AR, $\ddot{Y}$ AV, $\ddot{Y}$ AR, $\ddot{X}$
- 1 lateral gyrometer p
- 1 anemoclinometric probe linked to 3 pressure transducers (local kinetic pressure, incidence, sideslip)
- 1 coder-transmitter unit, PCM mode, 30 measuring tracks
- 1 cell for acquisition initialization and space-time synchronization
- 1 scanner for measuring the initial drop velocity
- 3 reference points for trajectory calculation
- internal powerpacks.

The accelerometers used are limited accelerometers with a frequency in excess of 800 Hz.

The gyrometer acts as a second level, with cut-off frequency of 45 Hz and absorption coefficient of 0.8.

The pressure transducers have their own frequency of
5000 Hz. The low-pass filters are interposed before coding and
emission. The longitudinal parameters ($\overset{\smile\smile}{Z}$ AV, $\overset{\bullet\bullet}{Z}$ AR, $\propto$ probe) are
low-pass filtered, cut-off frequency 150 Hz, fourth level with
the goal of avoiding scale-folding problems caused by the
sampling. The signals from the transducers are coded in PCM mode
at 12 bits, the frequency of the coder is 150 kbits/second, and
30 measuring tracks are available. Each parameter appears twice
in the cycle, which corresponds to a sampling period of 1.28 ms
(781 Hz).

2.3 - Vertical gust generator (Figure 5)

The vertical gust generator occupies at maximum the volume
left free by the lateral wind tunnel. It generates a stream
semi-guided by the two lateral return corridors; the working
section of the stream, located 2 m above ground, is 2.75 m high,
3.30 m wide, and 2.5 m long. It is inclined 4° from the vertical
to minimize the X component.

Three longitudinally distributed profiles of vertical
velocity were created for these tests (Figure 6): one of window
type, one of rising gradient type, and one of descending gradient
type. These three types of profiles allow us to test the
influence that frequency distribution at the entrance has on
model response. The maximum velocity for each profile is 2.5
m/s, which makes it possible to obtain a variation of incidence
compatible with the hypotheses of linearity of the model, while
allowing for the model velocity (35 m/s). These profiles were
formed through the use of flow distribution grates placed in the
blowing and suction chambers.

The profiles of gust types are identified by three series
of velocity measurements taken with a micro-windmill in three
parallel planes, situated on the flight symmetry axis and 0.25 m

to either side of the axis, at a height corresponding to the average passing altitude of the model in the wind tunnel. The repeatability and the stability of the gust over time have been verified, which guarantees that the gust crossed during the test conforms to the gust previously measured.

2.4 – Catapulted flight test station

In the general view of the testing installation (Figure 7), it is possible to distinguish the zone where wind velocity is increased and decreased using a pneumatic catapult, the free flight area where trajectories can be developed over the approximately 30 m of distance covered, and the model recovery zone. In the free flight area, the vertical gust generator makes it possible to create exterior stresses (incidence) on a length of 2.5 m.

The methods chosen for catapulting the model make it possible to obtain precise initial drop conditions, especially with respect to geometry, kinetics, dynamics (vibratory and instrumental aspects) and aerodynamics.

The initial longitudinal velocity at the time of drop is clearly defined using scanning barriers.

The data necessary for determining the trajectory and   /7
attitudes of the model in flight are obtained on three ground bases equipped with banks of scanners. Each base is situated in a vertical plane normal to the flight symmetry plane and includes two optical recording banks with photographic plates at perpendicular axes. Each base thus records the luminous reference trails made by the model, as well as a fixed local reference. The trails are picked up continuously. Pre-programmed triggered flashes make a freeze-frame of the model on

each photographic plate and activate a photocell on the model.
This photocell generates space-time synchronization data inserted
in the PCM telemetry cycle.

2.5 - Software for interpreting test results (Figure 8)

Two principal programs are used to process free flight data:

- a trajectory calculation program processes the luminous
  spatial reference trails made by the model, using data
  obtained by processing scanner recordings from the bases.
  From this are obtained the Euler angles, the center of
  gravity coordinates, and the velocity vector orientation
  for each base.

- a program for processing the telemetry data uses the values
  obtained from the difference between free flight and zero
  readings made under the catapult immediately before
  velocity is increased. The first unit of initial
  conditions is determined either by direct measurements
  (instantaneous values furnished by the transducers at the
  time of velocity drop) or by independent measurements
  (slope, attitudes, initial velocity, etc.).

The results obtained from these two independent sources of /8
information are then used in a test for validating data and for
final adjustment of the initial flight conditions. Trajectory
calculation data remain the most precise and make it possible to
establish points of coincidence with the integrated dynamic data.
Flights are valid when, for each variable, the coincidence occurs
inside the "precision tubes" defined by the geometric values.
Adjustments are made to the initial conditions of the flight (ψ,
θ, ϕ, X, Y, Z, first and second derivatives), taking into account
the confidence interval of each parameter.

Elsewhere, the IMFL is pursuing the development of another recovery method based on Kalman filtering.

3 - METHODS OF RESULT ANALYSIS AND AERODYNAMIC CHARACTERIZATION

3.1 - Research of impulse responses (AMD-BA)

Stationary coefficients, it appears, are absolutely not adaptable to modeling an aircraft penetrating a gust (Figure 9).

The moment of pitch is even opposite in sign to that which occurs in reality.

The standard methods of unsteady representation, developed especially at IMFL and based on dividing the aircraft into forward fuselage, wing, and tail section, give good results for civil aircraft but seemed to us to be poorly adapted for a delta wing.

This is why Avions Marcel Dassault has continued to use research on impulse responses as a method of aerodynamic characterization for a military aircraft penetrating a gust.

Once the impulse responses are defined, any type of gust can be considered the sum of impulses. If the aerodynamic phenomena are linear, the aircraft response to any type of gust will be the sum of the impulse responses, the integrals of which are the indicative responses.

The hypothesis of linearity is justified by the range of low incidences in practice.

The aircraft behavior can be characterized by a transfer function H (p) - (Figure 10).

p: Laplace variable

t: time variable

$E(p)$ or $e(t)$ — $\boxed{\begin{array}{c} H(p) \\ h(t) \end{array}}$ — $S(p)$ or $\Delta(t)$
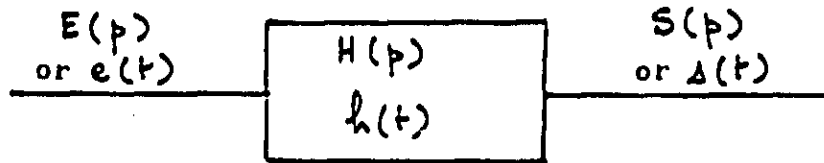
<u>input</u> = gust   <u>output</u> = aircraft response

Remember that the functions $F(p)$ and $f(t)$ are relinked in the equation by the Laplace transformation.

$$F(p) = \int_{0}^{+\infty} f(t)\, e^{-pt}\, dt$$

On the other hand, it is possible to write:

$$S(p) = H(p) \cdot E(p)$$
or
$$s(t) = h(t) * e(t)$$

*designates a convolution product.

In the case of vertical gusts, as the observed transversal moments in the tests are slight:

- sideslip $\beta \le 1°$
- lateral attitude $\phi \le 5°$

only the longitudinal components Cm and Cz are of interest.

Thus it can be written:

$$C_z(t) = C_{z_0} + C_{z_q}\cdot q(t) + C_{z_\alpha}(t) * \alpha(t)$$
$$C_m(t) = C_{m_0} + C_{m_q}\cdot q(t) + C_{m_\alpha}(t) * \alpha(t)$$

| coefficients measured at time t | unknown constant coef. | dynamic coef. linked to unknown pitch velocity | unknown unsteady coef. | incidence measured at time t |

Some authors propose the following representation:

$$C_z(t) = C_{z_0} + C_{z_q} * q(t) + C_{z_\alpha}(t) * \alpha(t)$$

$$C_m(t) = C_{m_0} + C_{m_q} * q(t) + C_{m_\alpha}(t) * \alpha(t)$$

We have not used this representation in the present case, because pitching velocity changes little in the gust.

To explain the convolution product, the following is used:

$$C_{z_m}(t) = C_{z_m 0} + C_{z_m q} \cdot q(t) + \int_0^{+\infty} \hat{C}_{z_m \alpha}(\tau) \cdot \alpha(t-\tau) d\tau$$

and to refine it:

$$C_{z_m}(t) = C_{z_m 0} + C_{z_m q} \cdot q(t) + \sum_{\lambda=0}^{p} C_{z_m \alpha_\lambda} \cdot \alpha(t-\lambda T)$$

This leads ultimately to resolution of the matrix equation:

$$AX = B$$

matrix of measured "angles of incidence"	matrix of unknown coefficients	matrix of measured coefficients
A (n, p + 3)	X (p + 3, 2)	B (n, 2)
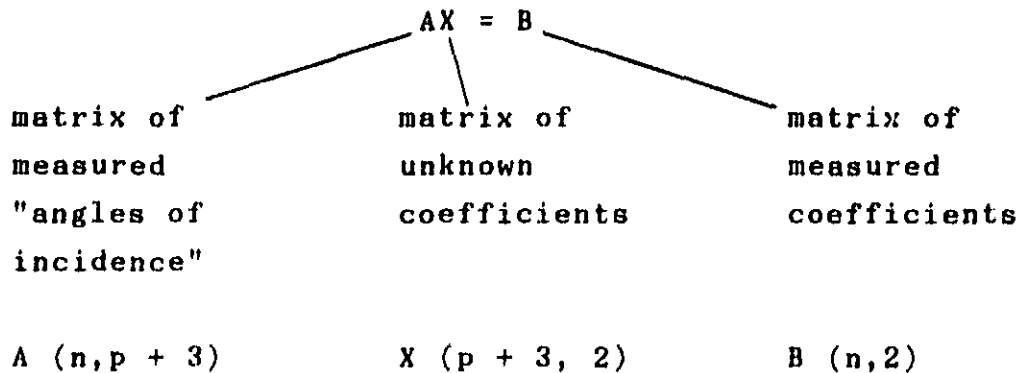
3.2 – IMFL Method of "local" coefficient identification

To study C.A.G. [expansion unknown] linked to free model tests involving crossings of short wave-length vertical gusts, the IMFL has systematically developed and is developing mathematical models for representing phenomena based on dividing the model into several sections. This method makes it possible to allow for the distribution of aerodynamic incidence on the aircraft.

For a model subjected to a gust of short length with respect to the length of the model, the profile of the vertical velocities is not uniform along the model. This statement leads to the consideration not of one single incidence, calculated at the model's center of gravity, but of a family of local incidences which makes it possible to allow for and to represent the rapidly variable aspect of the phenomenon. These local incidences are calculated at the geometric centers of the various sections (Figure 11).

3.2.1 - Model choice and equations

The hypotheses used for the remainder of the calculation are the following:

- the model is an unchangeable solid;
- the movement of the model is longitudinal;
- the gust is contained in the XOZ vertical plane, the symmetric plane of the model;
- the velocity of the model is constant in the module;
- all angles are considered small; /13
- the gust is permanent (stable during the time the model takes to cross the gust).

Longitudinal movement is described by the equations for lift and moment of pitch.

Projection on Gza

$$-mV\left(\dot{\alpha}-q\right) = -\frac{1}{2}\rho S V^2 C_z + mg$$

moment around the center of gravity

$$B\frac{dq}{dt} = \frac{1}{2}\rho S \ell V^2 C_m$$

13

The coefficients Cz and Cm are linearized with respect to incidence

$$C_z(t) = C_{z_0} + \sum_i C_{z\alpha_i} \cdot \alpha_i(t)$$

summation extended to all control points where local incidences are calculated.

$$\alpha_i(t) = \left(\alpha_{CDG} + \frac{w_i}{V} - q\frac{\ell_i}{V} \right)(t)$$

with α_{CDG} incidence with the ground calculated at the CDG

$\frac{w_i}{V}$ variation of the incidence introduced by the vertical gust, calculated at point i by applying a pure delay to the value measured by the anemoclinometric probe.

$q\frac{\ell_i}{V}$ influence of the pitching velocity

The local coefficients $Cz\alpha_i$ and $Cm\alpha_i$ are a result of /14 minimizing an object model distance criterion by least squares:

$$d = \sum_t \left[C_z(t) - \left(C_{z_0} + \sum_i C_{z\alpha_i} \cdot \alpha_i(t) \right) \right]^2$$

The coefficients thus identified are then introduced into the simulation.

3.2.2 - Simulation model

Using the formulated hypotheses, the longitudinal movement equations are written:

$$m V \frac{dV}{dt} = \frac{1}{2} \rho S V^2 \left[-\left(\sum_i C_{z\alpha_i} \frac{\ell_i}{V} \right) q + C_{z\alpha} \cdot \alpha + C_{z_0} + \sum_i C_{z\alpha_i} \frac{w_i}{V} \right] - m g$$

$$B \frac{dq}{dt} = \frac{1}{2} \rho S \ell V^2 \left[-\left(\sum_i C_{m\alpha_i} \frac{\ell_i}{V} \right) q + C_{m\alpha} \cdot \alpha + C_{m_0} + \sum_i C_{m\alpha_i} \frac{w_i}{V} \right]$$

$$q = \frac{d\gamma}{dt} + \frac{d\alpha}{dt}$$

14

The matrix form of the differential system is thus written:

$$\dot{x}(t) = \|A\| \cdot x(t) + \|u(t)\|$$

with:
$$x = \begin{pmatrix} q \\ \alpha \end{pmatrix}$$

$$\|A\| = \begin{pmatrix} -\frac{1}{2}\rho\frac{S\ell V}{B}\sum_i C_{m\alpha_i}\ell_i & \frac{1}{2}\rho\frac{S\ell V^2}{B}C_{m\alpha} \\ \frac{1}{2}\rho\frac{S}{m}\sum_i C_{z\alpha_i}\ell_i + 1 & -\frac{1}{2}\rho\frac{SV}{m}C_{z\alpha} \end{pmatrix}$$

$$\|u(t)\| = \begin{pmatrix} \frac{1}{2}\rho\frac{S\ell V^2}{B}\left(C_{m_0} + \sum_i C_{m\alpha_i}\frac{w_i}{V}\right) \\ -\frac{1}{2}\rho\frac{SV}{m}\left(C_{z_0} + \sum_i C_{z\alpha_i}\frac{w_i}{V}\right) + \frac{g}{V} \end{pmatrix}$$

3.3 – Choice of analysis parameters

This essentially concerns incidence. Three values are available:

α_{ground} = ground incidence: This is the angle made by the aircraft velocity vector and the horizontal fuselage reference.
These angles are of no interest for the unsteady aspect.

$\alpha_{\underline{p}} = \alpha_{ground} + \frac{w}{V}$: pressure measurement incidence

where w: gust velocity derived from pressure measurement.

and V: aircraft velocity

probe: incidence measured by the probe

15

The intensity of the gust, expressed as $\triangle Cz$ and $\triangle Cm$, varies with regard to pressure measurement incidence between tests conducted with the same gust. These differences are clearly more than measurement error.

On the other hand, a clear correlation is observed between the Cz and Cm effects of the gust and the probe incidence. This implies use of the latter for calculating impulse responses (Figure 12).

4 - VERIFICATION OF GUST DETECTION PROBES /16

4.1 - Behavior outside the gust

The first tests made with a spherical probe revealed a noise problem affecting incidence measurement. Analysis showed:

- that it was not a handling problem, as the noise also appeared on the electric signal.

- that it was white noise.

- that it was not electrical in origin. While the transducers are being set at zero, before increasing velocity, the signal does have the noise.

- that the increase of fluctuations with velocity during the acceleration phase on the launch ramp resembles aerodynamic noise (Figure 13).

Explaining the crest-crest incidence deviations of 1.5° requires velocity variations of 0.9 m/s; these are incompatible with "at rest" air conditions in a turbulence-free laboratory.

The conclusion is thus reached that the constant noise is definitely linked to the geometry of the probe.

A series of tests conducted at the CEAT S4 wind tunnel confirmed our conclusions and led us to adopt a probe with conical geometry (Gruson probe), the desired gain being approximately 2 (Figure 14).

Upon retesting in free flight, our expectations were surpassed. The fluctuations were brought to $\triangle \alpha \approxeq 0.3°$ crest-crest.

4.2 - Behavior in the gust

Tests for measuring probe response time were conducted at Chalais, Meudon. This dynamic standardization, which constitutes the identification of the internal dynamic response of the probe (entire unit - piping - transducer case - transducer), has no bearing on establishing the flow on the probe. For the Gruson probe, the delay taken into account for velocity and incidence signals is 3 ms (1 ms pure delay and 2 ms to climb to 10%).

In the unit, the comparison of probe incidence and pressure measurement incidences is quite good on window gusts, with, however, small deviations on the plateau value (0.4° max.). On the ramps, more significant deviations on the maximum values are noted (Figure 15). However, past records show that probe velocity increases about 1 m/s as the gust passes.

To solve these problems, work was done to characterize the overall dynamic behavior of the probes (aerodynamic aspect).

5 - PRESENTATION OF PRINCIPAL RESULTS

5.1 - Steady aspect

5.1.1 - Correlation with wind tunnel results

A catapulted flight with a gust includes four stages:

- one phase to lessen the transitory effects of the ramp (of
  no interest for this study);

- one phase of passage through the gust;

- two phases of quasi-permanent flight: one before and one
  after the gust (Figure 16).

The interest in these two last phases concerns the degree of
credibility of the measurements made, in comparison to results
obtained in other wind tunnels.

It can be confirmed (Figure 17) that values are similiar for:

- the lift gradient
- the polar curve opening
- the position of the center

The Fauga results, which stand out, are perfectly explained
by the influence of the Reynolds number.

The wind tunnel curves are reset based upon the null lift
values $(C_{xo}, \delta_{mo}, \alpha_o)$ of the free flight.   These parameters are
a function of the mounting and especially the permeability of the
model.

5.1.2 - <u>Repeatability</u>   <u>/19</u>

Another credibility criterion for the measurements made
concerns the repeatability of results; as every experimenter
knows, two experiments reputed to be identical do not always give
the same results.

From this point of view, the following can be considered
satisfied:

$$\Delta\alpha \simeq \pm 0.15°$$

$$\Delta\delta m \text{ balance} \simeq \pm 0.1°$$

$$100 \Delta C_x \simeq 0.2$$

(Figure 18)

These values were obtained by constantly improving test procedures, as well as by more specific concentration on elevon rigidity and precision of aileron display; this last parameter is very noticeable for an aircraft with delta wings.

5.2 - Unsteady aspect

5.2.1 - Impulse method (AMD-BA)

The unsteady results are themselves encouraging, as the indicative responses converge well on the steady gradients in most cases (Figure 19).

However, there is still some noise, and identification in the case of some flights gives unsatisfactory results:

- significant oscillations (Figure 20)
- non-convergence

An investigation of these problems is under way, in   <u>/20</u>
particular with respect to the impact of structural noises, behavior of gust detection (probe), etc.

5.2.2 - Sectional method (IMFL)

The results presented in Figures 21 and 22, comparing the Cz and Cm obtained in flight to those obtained in simulation with an

19

overall model (one section) or a model in sections, require the
following remarks:

- the overall model, as predicted, does not follow real
  behavior, especially in pitching response;

- with a model cut into 14 sections, behavior in pitching-
  pumping is very well restored.

During its development, this method was the subject of
additional studies which make it possible to identify especially:
the effect of the number of sections, the eventual physical
significance of the coefficients, and the durability of the model
with regard to various gust entrances.

6 - <u>GENERAL DISCUSSION OF RESULTS AND DEVELOPMENT</u>   <u>/21</u>
    <u>PERSPECTIVES</u>

The experimental method is proven to be well adapted for
unsteady aerodynamic characterization in vertical gusts.

The need for the launched probe to take gust intensity into
account in the various analysis methods indicates that more
complete verification is necessary, especially in dynamics.

The balanced characteristics are heightened beginning with
flights outside of gusts, which constitutes a given reference
with respect to wind tunnel results.

From an unsteady point of view, the first results are
satisfactory. The development perspectives presented for
analysis methods and aerodynamic characterization are encouraging
and give rise to the necessary investigations.

On the bases presently established, it is possible to simulate an aircraft's behavior in turbulence given its design. This makes it possible to envision treatment of problems concerning behavior optimization through the concept of generalized automatic control.

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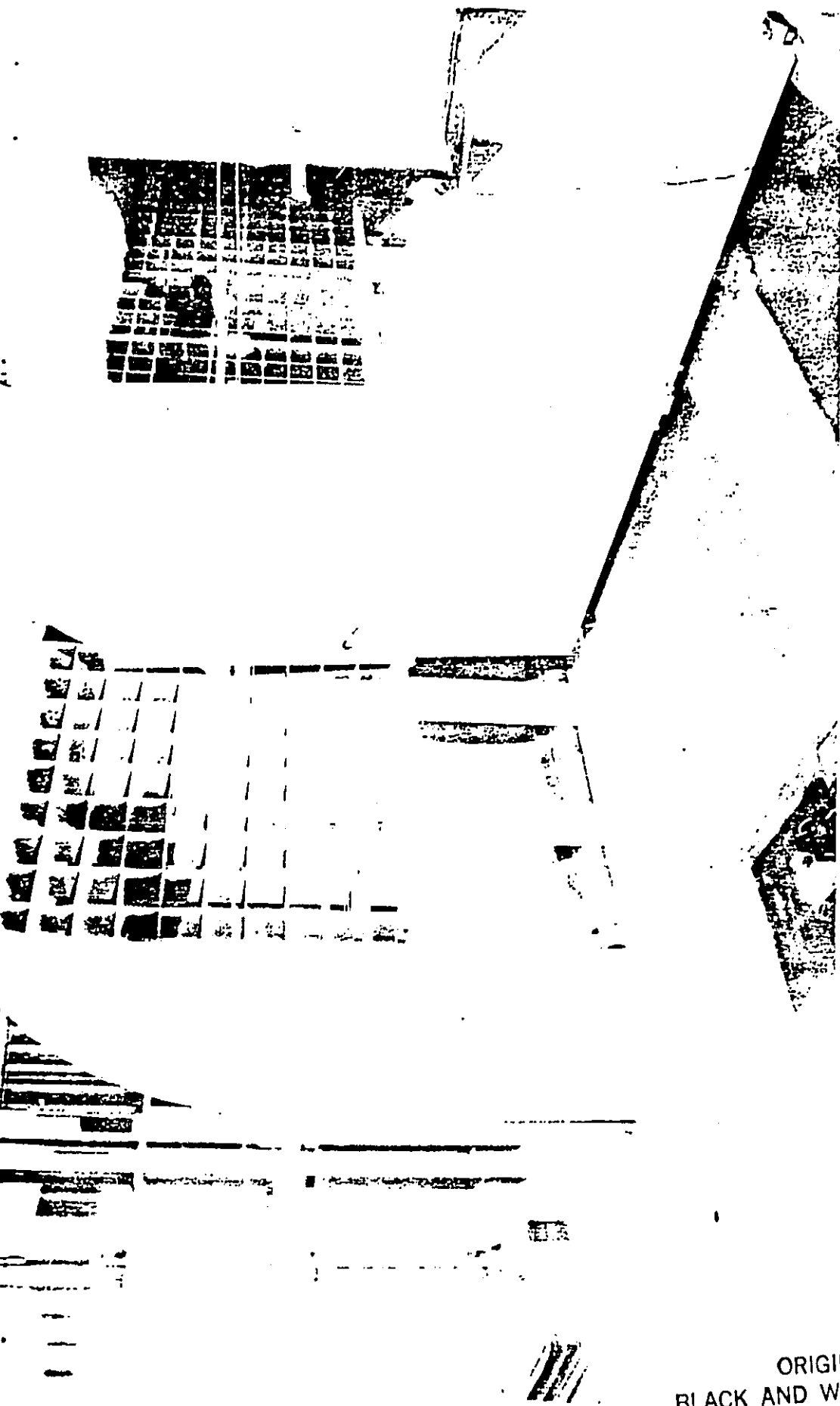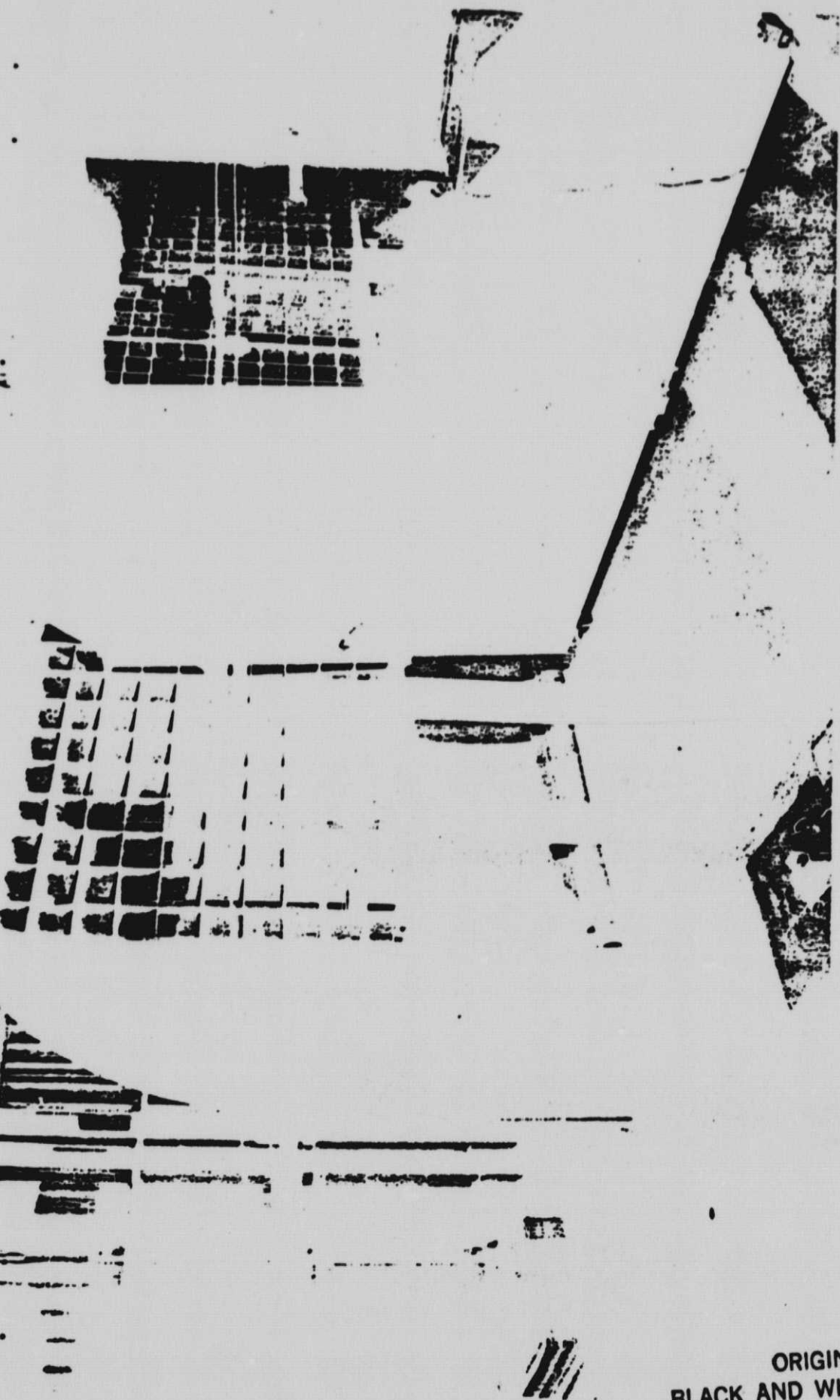
A major factor in selection of the Lockheed team was the fully integrated management structure that established clear relationships between the organizational elements of the Shuttle Processing Contractor and the work to be performed. Lines of communication, authority, and responsibility were directly drawn between top management and the organizational elements. Personnel of other team members--particularly Grumman--were (and are) integrated throughout the organization, along with the functional assignment of Vandenberg Air Force Base operations to Morton-Thiokol, Integrated Ground Operations to Grumman, and Program Requirements Analysis to Pan Am.

With the transition period approximately at the half-way point, it is too early to reach any definitive judgment as to the operational effectiveness of the emerging organization. However, it is possible to identify certain features or principles of the Lockheed plan that indicates a recognition of the challenges and problems in both the near and longer-term. For example:

--A recognition, as stressed by the SPC's top management, that maintenance and well-being of the work force is essential to productive and safe operations. High morale among employees and attention to detail must be sustained for the operational life of the space transportation system, no matter how routine and predictable operations become in the later years.

--Creation of an external Safety Advisory Board (modeled in many respects after the ASAP) that will meet at least quarterly to examine all aspects of the SPC's operations from a safety perspective. Direct access to SPC top management is assured. The desirability of direct communication between this new Safety Advisory Board and the Panel was informally discussed in December.

--Recognition of the need for a common logistics system to support operations at both Kennedy Space Center and Vandenberg Air Force Base. SPC management currently views logistics as its most serious and difficult problem. This responsibility is

17

Figure 2

PHYSICAL SIMILARITY

GEOMETRIC SCALE OF MODEL, MODEL BLADE/AIRCRAFT BLADE

RATIO OF VOLUMIC AIRMASSES, ZERO ALTITUDE OF MODEL FLIGHT, ALTITUDE OF AIRCRAFT FLIGHT

| VARIABLE	DIMENSION	RELATIONSHIP
LENGTH	L	λ
MASS	M	$m\lambda^3$
TIME	T	$\lambda^{0.5}$
SURFACE	L^2	λ^2
VOLUME	L^3	λ^3
VELOCITY	LT^{-1}	$\lambda^{0.5}$
ACCELERATION	LT^{-2}	1
FREQUENCY	T^{-1}	$\lambda^{-0.5}$
INERTIA	ML^2	$m\lambda^5$
FORCE	MLT^{-2}	$m\lambda^3$
MOMENT	ML^2T^{-2}	$m\lambda^4$
PRESSURE	$ML^{-1}T^{-2}$	$m\lambda$

hampered by NASA's own ambiguity concerning a total logistics, spares, and maintenance program. The SPC has no responsibility for ordering or budgeting spares acquisition. It is also not SPC's responsibility to plan major or minor maintenance "downtime" for Orbiter refurbishment. This must be resolved if the logistics system is to adequately support operations.

--An expressed determination to drive operating decisions to the lowest possible level in order to (1) strengthen responsibility at the hands-on level and (2) take advantage of the expertise and knowledge of those persons actually doing the work. Day-to-Day instructions are not to come from top management.

--Recognition of the lack of commonality among the Orbiters and the related assumption that maintenance and logistics procedures must take these differences into account for the life of the program.

--The decision to work toward zone-type processing of the Orbiter where a particular area is worked completely and closed-out only once, as distinct from the present system of numerous close-outs as individual systems are processed separately. Related to this approach is the objective of assembling all needed instructions and parts in the immediate location or station where the work is to be performed.

--Establishment of direct links between the SPC's planning organizations--Program Requirements Analysis, Mission Management Office, and Software Integration Office--with comparable Level III entities at NASA. These direct communication channels will facilitate technical expertise being readily available and provide channels of information for NASA to observe element performance and share in the decisions to further simplify "turnaround" procedures.

18

Figure 3
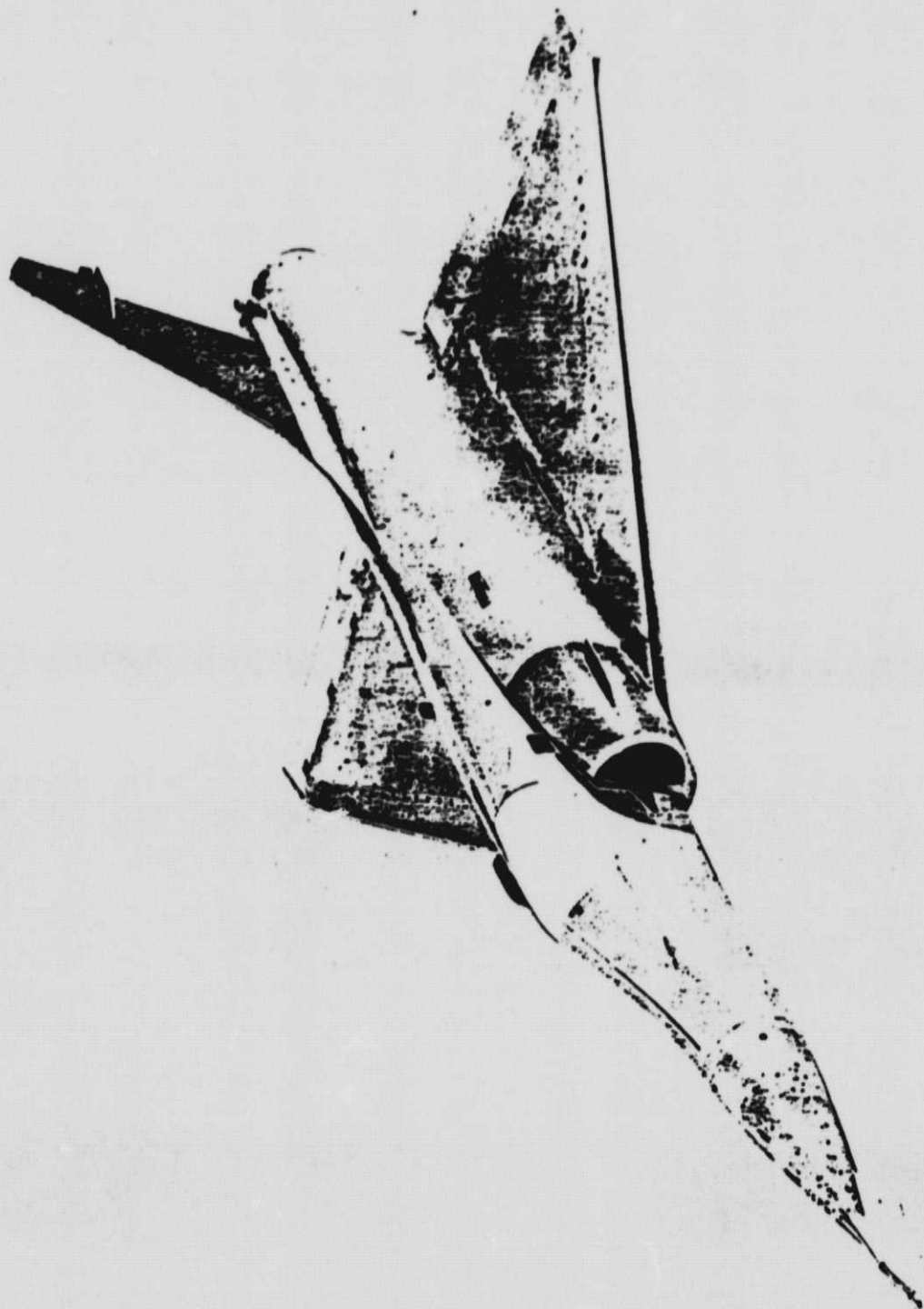
EXPERIMENTAL MODEL

These various organizational arrangements and operating principles will be monitored by the Panel as they are implemented. Nevertheless, they provide evidence at this juncture of a management approach that appreciates the continuing risks and difficulties of Shuttle processing, as well as the opportunities to develop a more efficient and cost-effective operation.

NASA'S Support of the Shuttle Processing Contractor (SPC)

In prior annual reports and in other reports to NASA management, the Panel has emphasized the importance of moving toward an organizational arrangement within NASA that takes account of the special needs of the Shuttle's routine, more nearly commercial type, operation as distinguished from the prior research and development effort. In July 1982 we noted, for example, that a "well-defined and stable organization within NASA to oversee STS operations is the anchor for the SPC." The selection of the SPC and initiation of its responsibilities makes this observation more timely and pertinent than ever.

Last year the Panel suggested that the "organizational arrangement within NASA that is to be responsible for commerical operation of the Shuttle should be determined and announced, even though full implementation of this arrangement might not be feasible for the next several years." The Panel's assessment of the current status of the Shuttle Processing Contractor indicates why this recommendation still merits consideration. For example:

--The interim logistics procedure now in effect essentially continues control of all flight hardware with Johnson Space Center and Marshall Space Flight Center. While this arrangement is appropriate for the immediate period when the SPC is building its capabilities and establishing a confidence level among NASA managers, the time is fast approaching when retention of this control by research and development centers will more than likely

19

Figure 4

MODEL CHARACTERISTICS AND EQUIPMENT

PHOTO CELL

spot

q, α, β
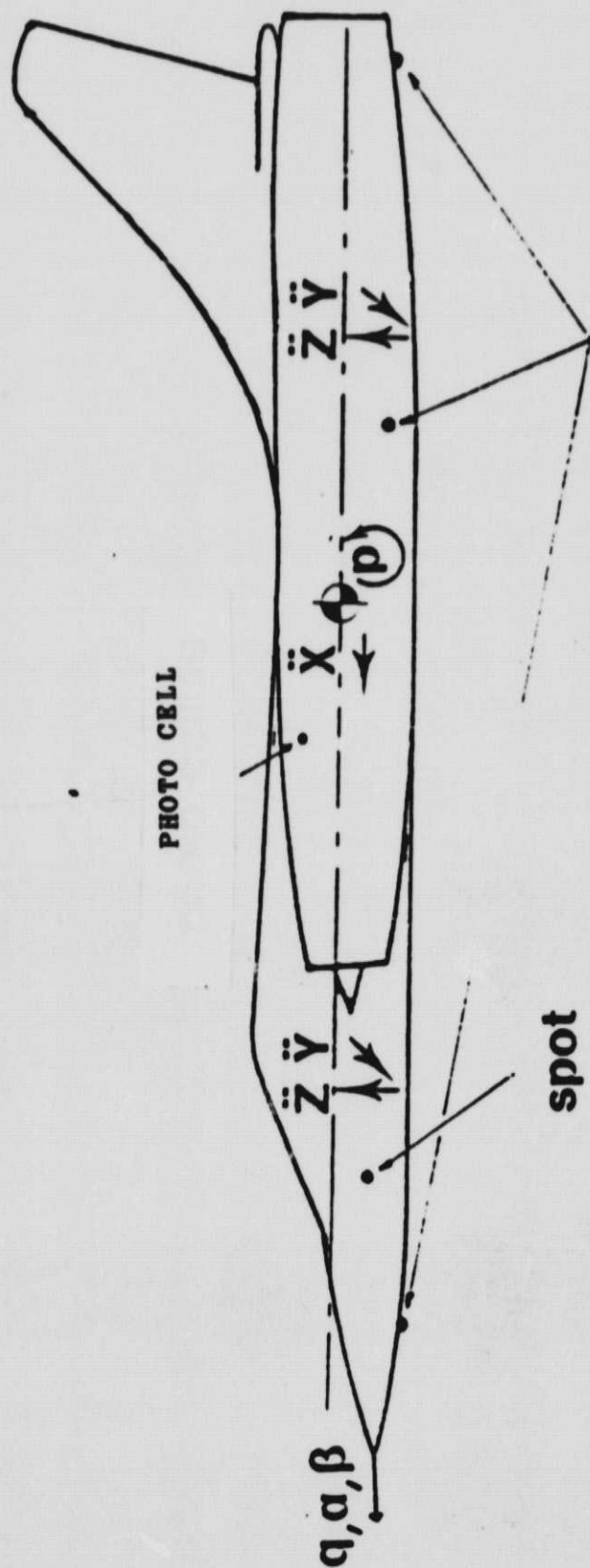
LUMINOUS REFERENCE POINTS

SCALE   1/8.6

BLADE   0.965 m

SURFACE   0.554 m²

MASS   20.3 kg

A 0.43 m²·kg

B 2.50 m²·kg

C 2.75 m²·kg

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AND WHITE PHOTOGRAPH

impede processing operations. Planning should begin now for an orderly transfer of this oversight responsibility within NASA to an STS operations entity.

--A comprehensive maintenance plan for the Orbiter is lacking. NASA's Operations and Maintenance Instructions (OMI's) provide maintenance procedures but not a baseline from which risks can be assessed. Preparation of such a plan would undoubtedly be a priority assignment of an STS operations entity, carried out in collaboration with Johnson Space Center, Marshall Space Flight Center and the new Shuttle Processing Contractor.

--Operational problems of some magnitude can be expected for the SPC once the Vandenberg launch facility is activated. For example, conflicts between NASA and the USAF for priority of spare parts and perhaps ground support equipment will have to be resolved if the SPC is to carry out its processing responsibilities on both coasts. Resolution of these problems will be facilitated by the existence of an STS operations entity within NASA.

--Flight schedules at KSC and VAFB should be established that permit the SPC to deploy its human and material resources in a cost-effective manner.

--The SPC should participate in the review process that leads to major hardware acquisitions and enhancements that relate to Shuttle processing activities.

The Panel is encouraged by the approach and apparent organizational and technical capabilities of the SPC. The preparation for this significant step toward achieving a genuine operational space transportation system has been thorough and sensibly carried out. Both NASA and the Lockheed team, along

VERTICAL GUST GENERATOR

3.3m

2.75 m

W=2.5m/s

2.5 m

5.9 m
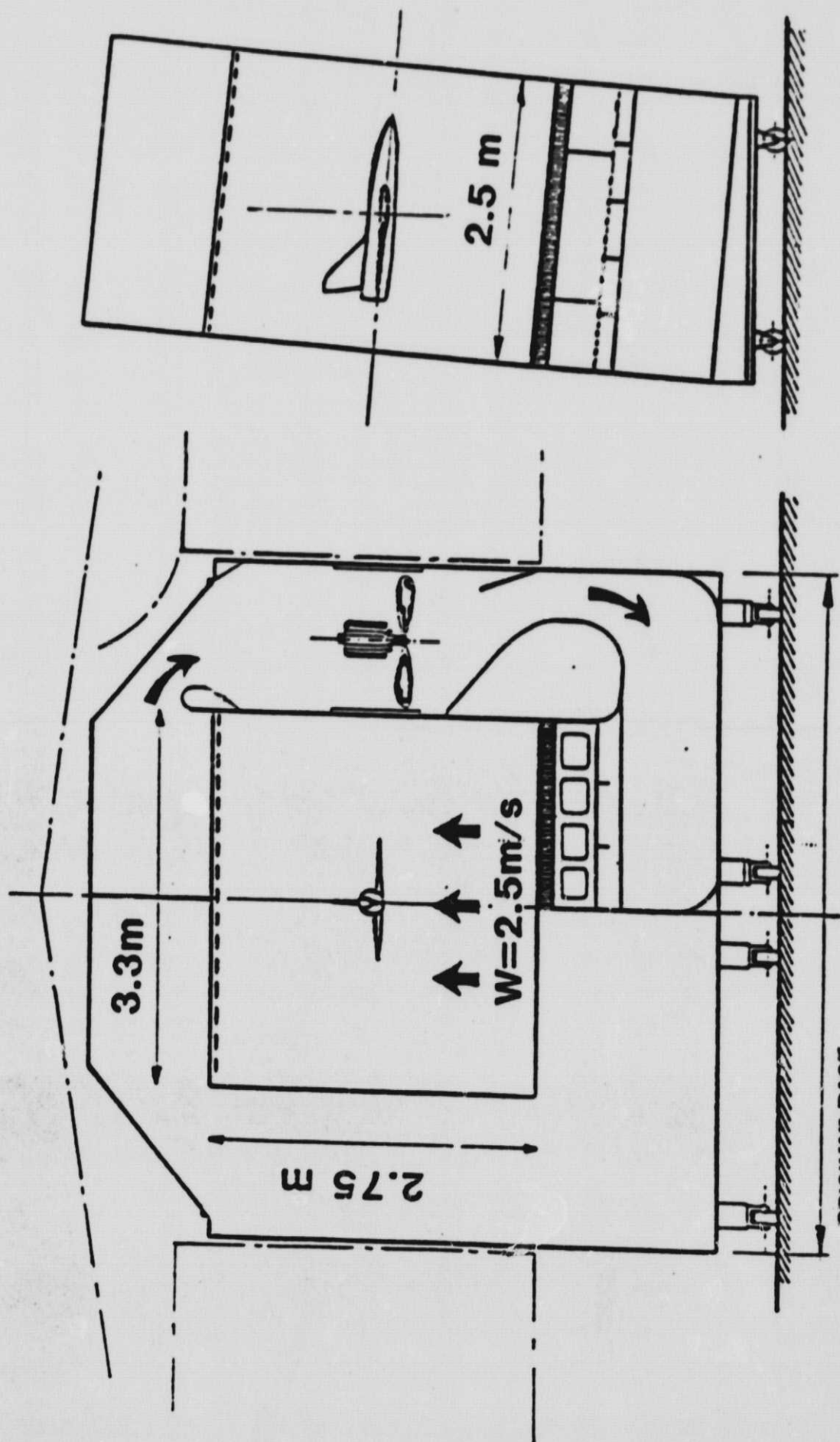
Figure 5

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

with the incumbent contractors, have contributed to this generally positive situation. As noted above, however, the Panel will continue to monitor these activities as the SPC assumes its full responsibilities and as the flight rate accelerates.

Figure 6

GUST INPUTS

slopes

window

1 m

1 m/s

theoretical profile
Pressure measurement limits

upper

lower

Frequency Responses

0.4

0.2

Hz

60

Hz

60

NASA RESPONSE TO CY 1982
REPORT

GEOMETRY OF FLIGHT SPACE

CATAPULT

4.5 M

d'

d'

d'

PROPULSION

FREE FLIGHT 30 m

RECOVERY

19 m

10.5 m

4.5 m

12.5 m

TRAJECTORY CALCULATION

Figure 8

GROUND MEASUREMENTS

OPTICAL TRAJECTORY CALCULATION

DATA SPATIAL REFERENCE TRAILS
MODEL FOR SEVERAL
RECORDING BASES
SCALES AND GEOMETRIC
DEFINITION

MODEL MEASUREMENTS

PCM DYNAMIC RECORDINGS

DATA ACCELEROMETRY,
GYROMETRY, ANEMO-
CLINOMETRY, GOVER-
NING POSITIONS,
SPACE-TIME SYNCHRO
TOPS

RESULTS AT THE MOMENT OF MEASUREMENT,
FOR EACH BASE, VALUE OF EULER'S
ANGLES, OF CDG COORDINATES, AND
OF THE SPATIAL SLOPE'S DIRECTING
COSINES

INITIAL
VELOCITY
AND
CONDITIONS
AT
PITCHING

TREATMENT - VALIDATION TEST

(COMPARISON GROUND MEASUREMENTS/CALCULATIONS FOR
EACH BASE, ELABORATION OF CORRECTIVE TERMS FOR
INTIAL CONDITIONS, ACCORDING TO THE MEASUREMENT
PRECISION CRITERIA)

RESULTS FOR EACH MOMENT OF SAMPLING, EULER'S
ANGLES, CDG COORDINATES AND THE FIRST AND
SECOND DERIVATIVES OF VELOCITY, INCIDENCE,
SIDESLIP, GOVERNING AILERON MOVEMENTS

ELABORATION OF STATUS VARIABLES AND AERODYNAMIC CHARACTERISTICS

Figure 8

GROUND MEASUREMENTS   MODEL MEASUREMENTS

OPTICAL TRAJECTORY CALCULATION   PCM DYNAMIC RECORDINGS

DATA   SPATIAL REFERENCE TRAILS   **DATA**   ACCELEROMETRY,
           MODEL FOR SEVERAL   GYROMETRY, ANEMO-
           RECORDING BASES   CLINOMETRY, GOVER-
           SCALES AND GEOMETRIC   NING POSITIONS,
           DEFINITION   SPACE-TIME SYNCHRO
                                                    TOPS

RESULTS   AT THE MOMENT OF MEASUREMENT,
              FOR EACH BASE, VALUE OF EULER'S
INITIAL   ANGLES, OF CDG COORDINATES, AND
VELOCITY   OF THE SPATIAL SLOPE'S DIRECTING
AND   COSINES
CONDITIONS
AT | TREATMENT - VALIDATION TEST |
PITCHING   (COMPARISON GROUND MEASUREMENTS/CALCULATIONS FOR
              EACH BASE, ELABORATION OF CORRECTIVE TERMS FOR
              INTIAL CONDITIONS, ACCORDING TO THE MEASUREMENT
              PRECISION CRITERIA)

RESULTS   FOR EACH MOMENT OF SAMPLING, EULER'S
              ANGLES, CDG COORDINATES AND THE FIRST AND
              SECOND DERIVATIVES OF VELOCITY, INCIDENCE,
              SIDESLIP, GOVERNING AILERON MOVEMENTS

| ELABORATION OF STATUS VARIABLES AND AERODYNAMIC CHARACTERISTICS |

Figure 9

Figure 9

RESEARCH OF IMPULSE RESPONSES

$$E(p) \text{ or } e(t)$$

INPUT = GUST

$$H(p)$$

$$h(t)$$

IMPULSE RESPONSE

$$S(p) \text{ or } s(t)$$

OUTPUT = AIRCRAFT
RESPONSE

$$\underset{m}{Cz}(t) = \underset{m}{Cz_o} + \underset{m}{Cz_q} \cdot q(t) + \sum_{i=0}^{p} \underset{m}{Cz_{\alpha_i}} \cdot \alpha(t-iT)$$

OVERALL RESOLUTION $\longrightarrow$ AX = B

$$A(n,p+3)$$
$$X(p+3,2)$$
$$B(n,2)$$

continuing concern for the structural integrity of the Orbiter at
its full payload capability and we are following NASA's flight
planning to assure ourselves that adequate placards are in place
until the structural loads and strength capability have all been
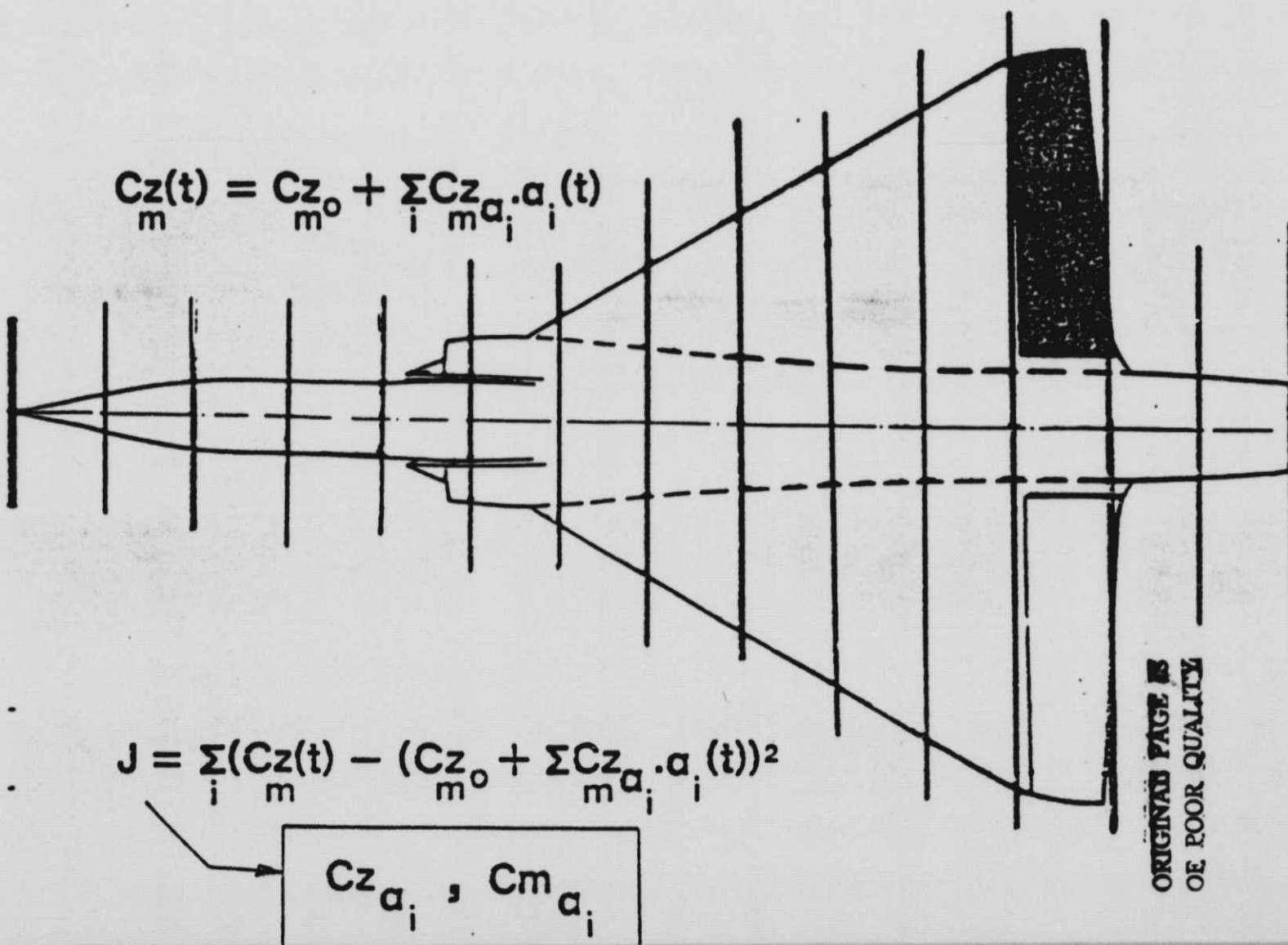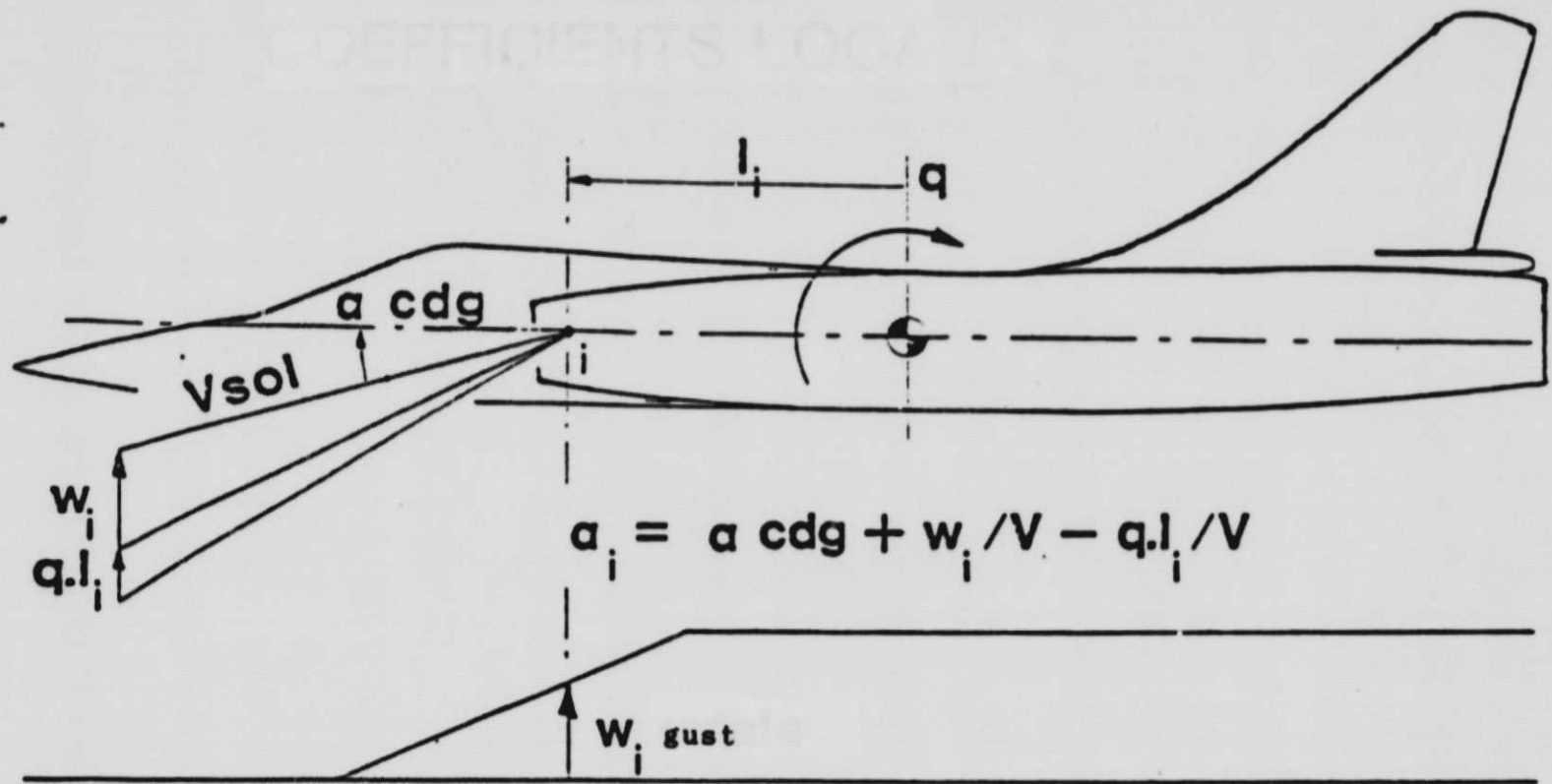defined.

Other Issues

Automatic entry and automatic braking:

The Aerospace Safety Advisory Panel accepts NASA's response
that a complete automatic reentry implies many change in ground
control concepts and manual inhibit responsibilities for the
crew, and the Panel agrees that the likelihood of incapacitation
of the entire crew is remote. Such a response does not cover the
more detailed suggestion that automatic gear deployment and
auto-braking should be considered to provide redundancy at a
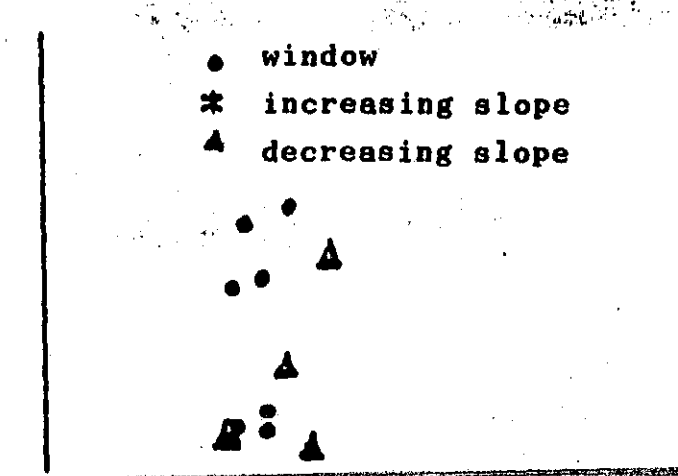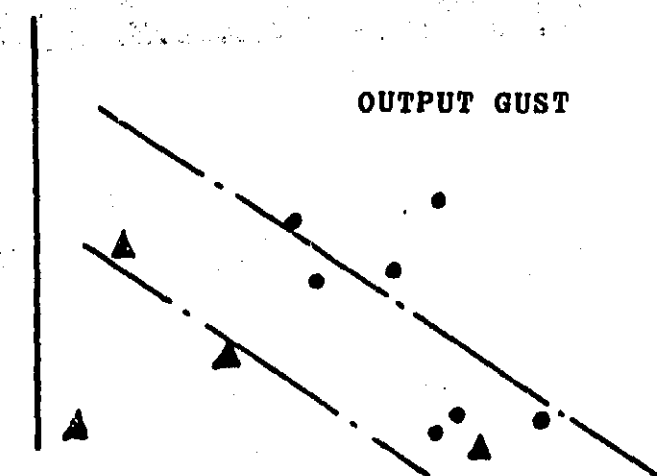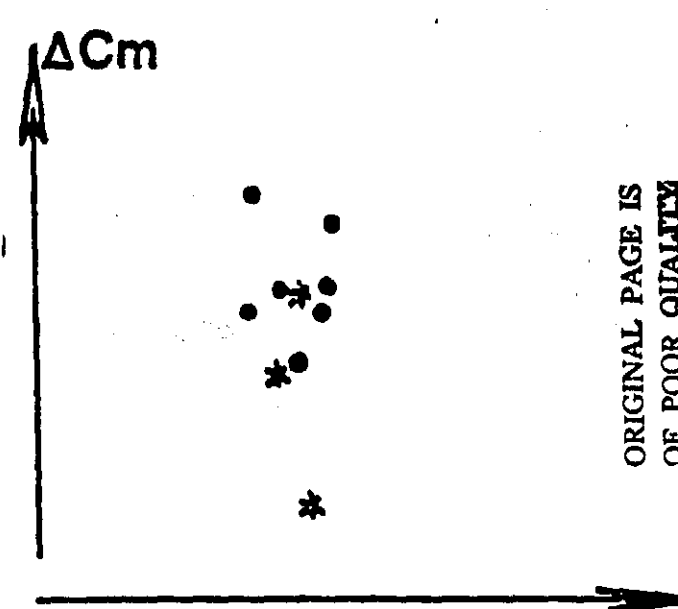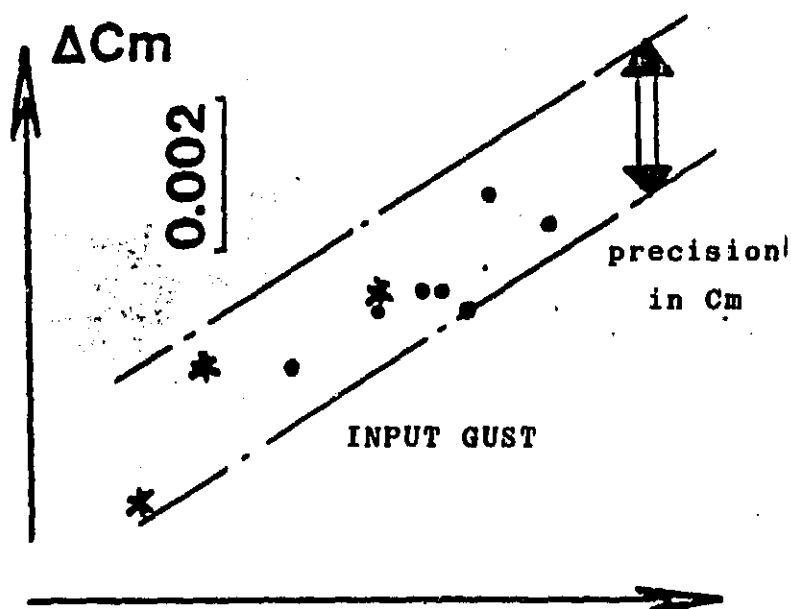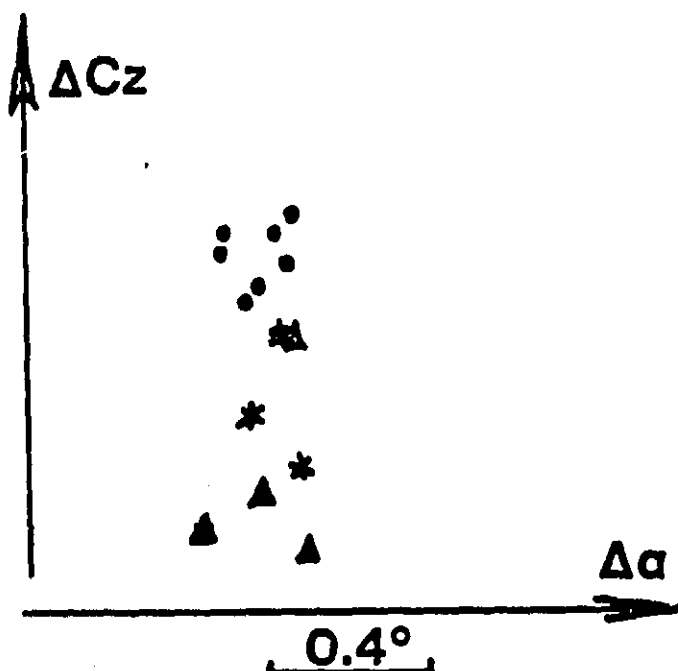critical time.

Role of crew vs. ground control:

NASA response indicates progress toward more autonomous crew
responsibilities and the ASAP commends such efforts. Separating
the various segments of the operation into launch, on orbit and
entry is useful in analyzing crew responsibilities and should be
continued. The ASAP included one other phase in its discussions
and that was the phase of flight readiness prior to launch. It
is the Panel's suggestion that some simplification in procedures,
some added confidence in on-board instrumentation, and some time
saved might be possible if the cockpit were used as a major
readiness check station in much the same manner as the cockpit of
a complex airliner or combat aircraft is used.

Figure 11

FINDING LOCAL COEFFICIENTS

$$a_i = a\,cdg + w_i/V - q.l_i/V$$

$$Cz_m(t) = Cz_{m_0} + \sum_i Cz_{m_{a_i}}.a_i(t)$$

$$J = \sum_i (Cz_m(t) - (Cz_{m_0} + \sum Cz_{m_{a_i}}.a_i(t))^2$$

$$Cz_{a_i}, \; Cm_{a_i}$$

SENSOR INCIDENCE

PRESSURE MEASUREMENT INCIDENCE

ΔCz

0.02

precision in Cz

$\Delta \alpha$

0.4°

ΔCz

$\Delta \alpha$

0.4°

ΔCm

0.002

precision in Cm

INPUT GUST

ΔCm

OUTPUT GUST
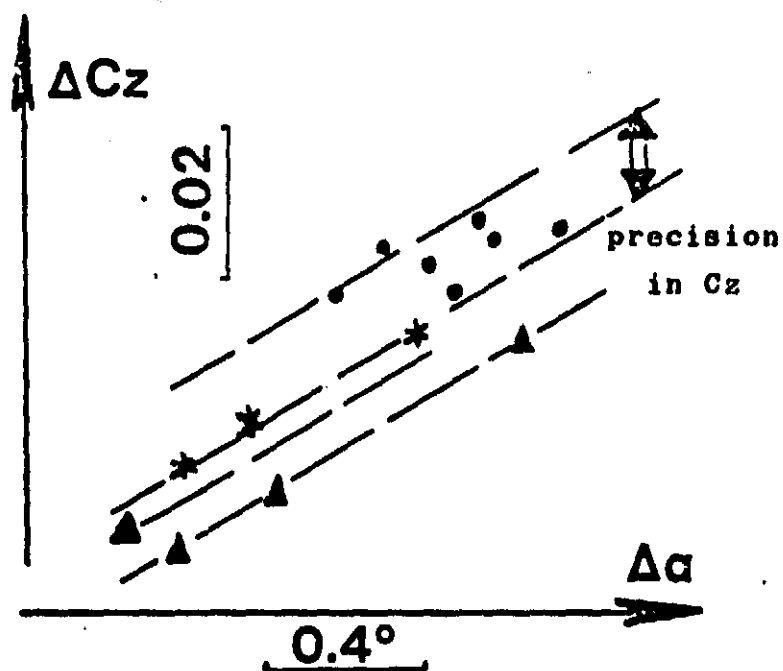
● window
✱ increasing slope
▲ decreasing slope

Figure 13

GROSS PROBE SIGNALS

Figure 14

SENSOR BEHAVIOR OUTSIDE GUST

spherical probe

conical probe

free flight
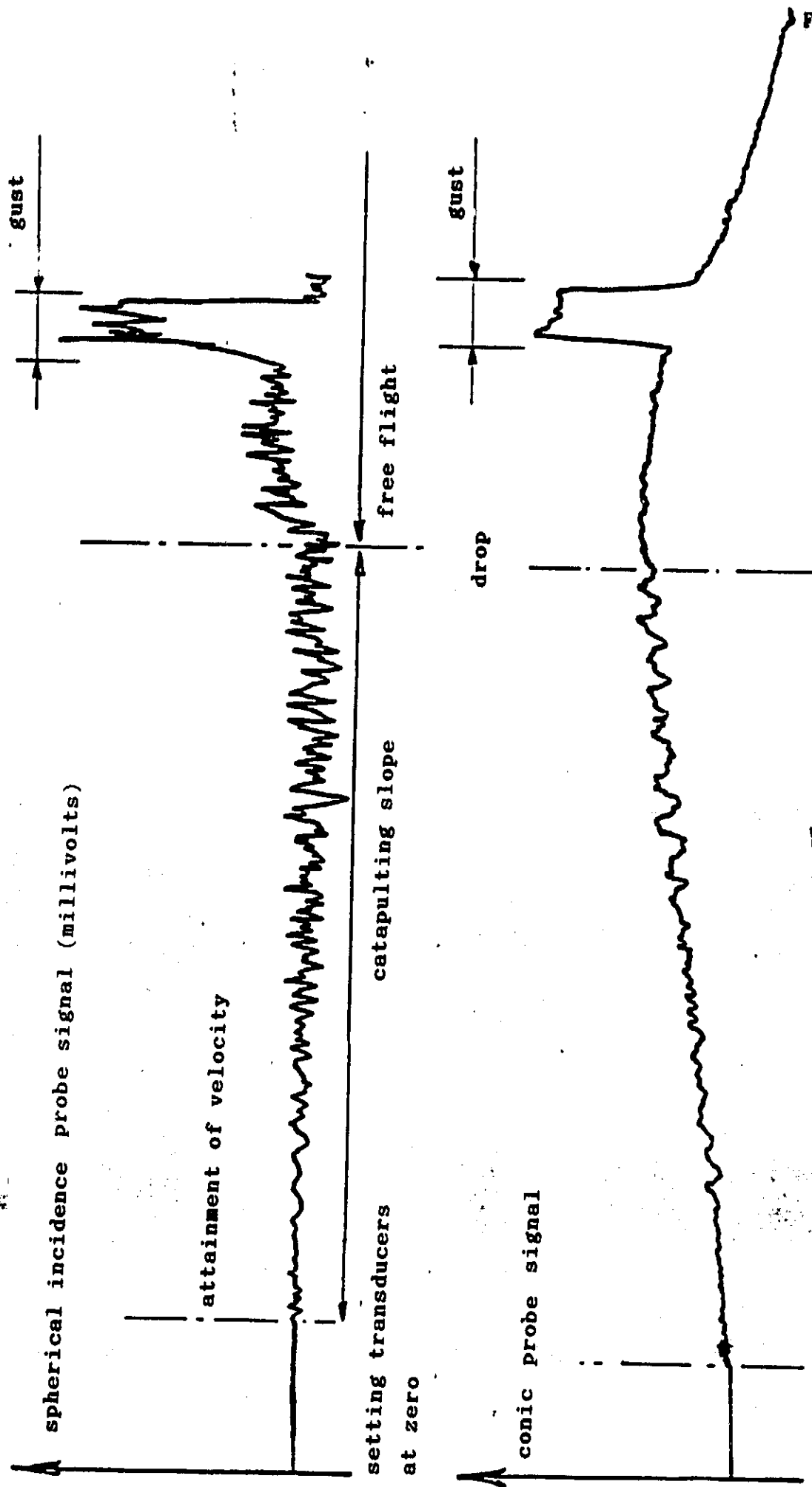
wind tunnel
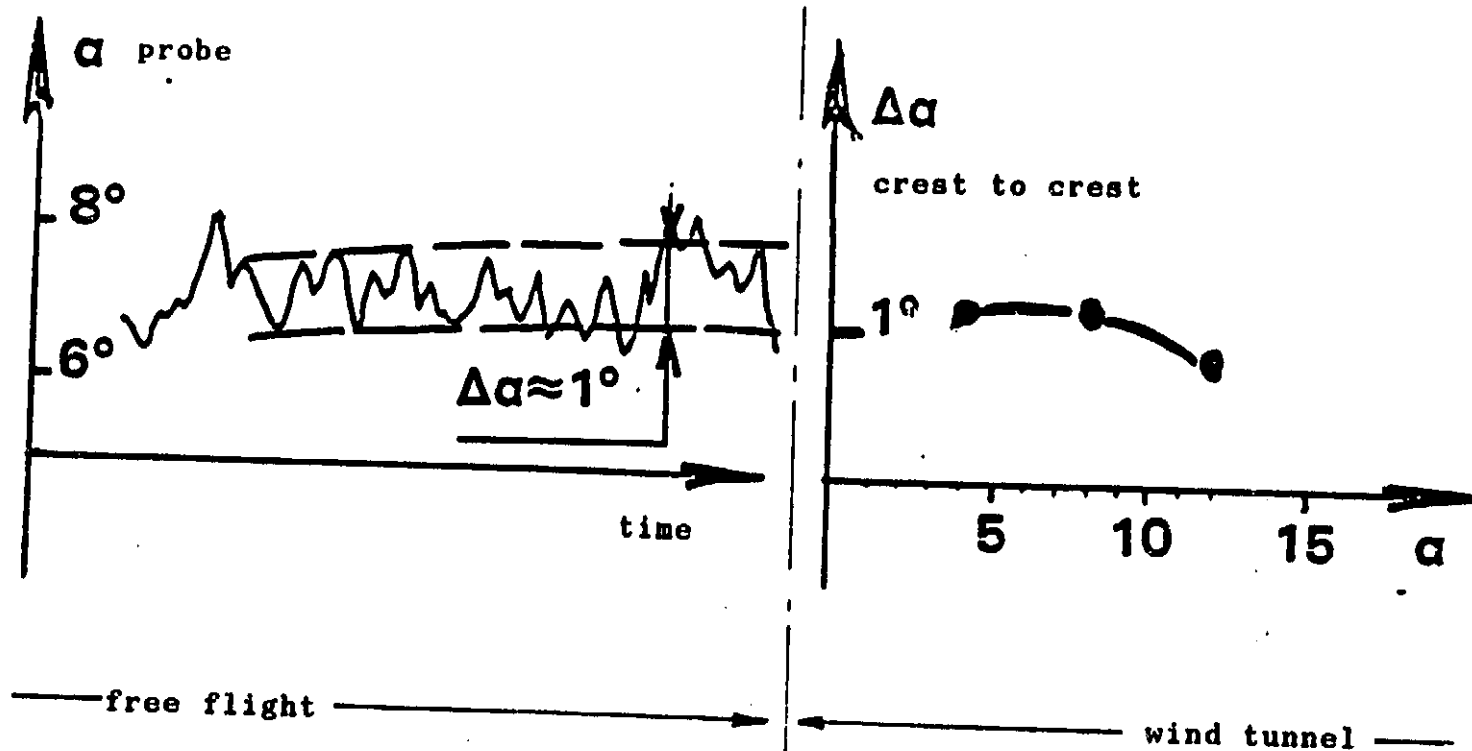
ORIGINAL PAGE IS
OF POOR QUALITY

PROBE BEHAVIOR INSIDE GUST

Figure 15

Probe velocity

Ground velocity

100ms

1 m/s

Pressure measurement incidence

Probe incidence

2°

Figure 16

Figure 16

HISTORICAL

Quasi-permanent flight

Slope transition

Quasi-permanent flight

Gust

Quasi-permanent flight

Cz

Cm

Ground incidence

Pressure measurement incidence

Probe incidence

Time

100 ms

0.2

0.02

2°

COMPARISON FREE FLIGHT WIND TUNNELS

balanced curves

S4 and S5 Wind tunnels

scale model 1/8.6

FAUGA Wind tunnel

scale model 1/4.28

Free flight

scale model 1/8.6

Figure 17

REPEATABILITY 10 FLIGHTS Balanced Coefficients

Figure 18

$\Delta\alpha \approx \pm 0.15$

Cz

$\Delta\delta m = \pm 0.1$

Cz

$\Delta Cx \approx 0.002$

Cz

α

δm

Cx

Figure 19

PITCHING

LIFT

Impulse responses

Impulse responses

$Cm\alpha$

$Cm\alpha$

$Cz\alpha$

$Cz\alpha$

steady gradient

steady lift gradient

Figure 20

PITCHING

LIFT

Impulse responses

Impulse responses

steady gradient

steady lift gradient

$C_{m\alpha}$

$C_{m\alpha}$

$C_{z\alpha}$

$C_{z\alpha}$

Figure 21

VERTICAL GUST MODELING

O   Free flight

■   1-section model

▲   14-section model

Cz

0.10

100ms

Time

Figure 22

VERTICAL GUST MODELING

o   Free flight

■   1-section model

▲   14-section model

100ms

0.01

Cm

Time

Appendix 4

EXTRAVEHICULAR ACTIVITY

Suits and prebreathing

Extravehicular activity (EVA) is increasing as the STS
project reaches out with new and more sophisticated programs.
All EVA has been conducted to date using a 4.3 psi suit. As far
as the Aerospace Safety Advisory Panel is aware, all EVA
activities have been routine except for the first flight. The
current suit, because of its low operating pressure, requires an
extensive period of prebreathing of 100% oxygen (up to 4 hours)
prior to attempting an EVA from a 14.7 psia cabin. This
precaution is necessary to avoid decompression sickness (bends)
of astronauts when going EVA.

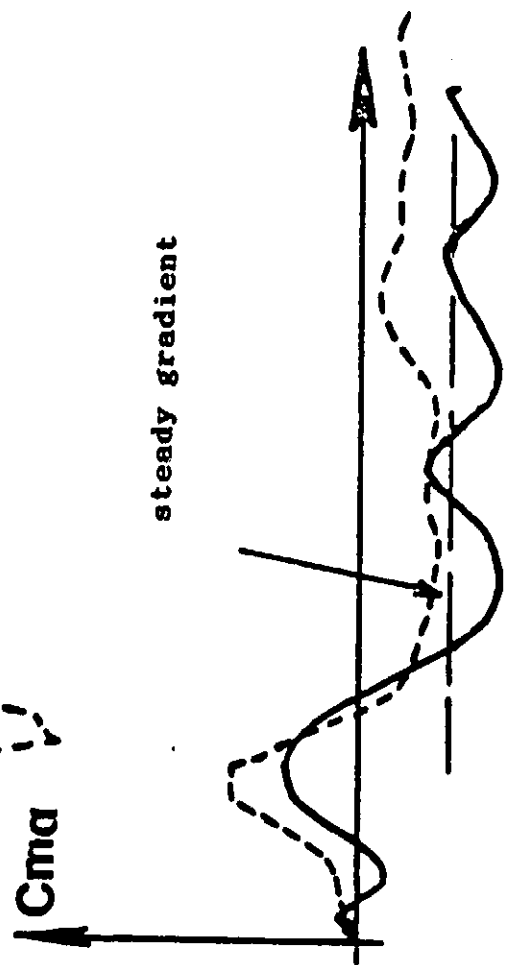On mission 41-B (STS-11) the cabin pressure will be reduced
from the normal 14.7 psia to 10.2 psia before initiating EVA to
acclimate the astronauts to the lower pressure. This allows
prebreathing time be reduced to about 40 minutes as well as
decreasing the astronaut's susceptibility to decompression
sickness.

For the future, research is being conducted on a higher
operating pressure suit at 8+ psi. This new suit design is to
have much greater flexibility in the shoulder, arm, and leg
joints, than that of the current suit. The new design has the
capability of greatly reducing or eliminating prebreathing
requirements.

It is the view of Aerospace Safety Advisory Panel that as
time progresses there will be an increasing need for the higher
pressure more flexible suit. While current NASA plans may not
require this new design, we can visualize the increasing need for
it as missions become more complex and the Air Force begins to

use the STS for its own missions. The ability to go EVA with little or no prebreathing is a big plus. The greater flexibility of the new design when combined with the proven torso of the existing design should decrease workload of the astronaut and reduce his susceptibility to decompression sickness.

We believe that NASA should foster the full development of the higher pressure suit and when fully tested it should become the standard suit for all future EVA activities.

Manned maneuvering unit

This short range versatile spacecraft, the manned maneuvering unit (MMU), has been conceived for use as a controllable platform which can transport an astronaut on a short radius from the Orbiter payload bay to satellites near the Orbiter or to inspect the external surfaces of the Orbiter itself. The purpose for the transportation of the astronaut is to place a member of the crew in a position to inspect, repair, and help retrieve satellites whose orbits can be reached by the Shuttle. Sufficient control power is designed into the MMU to permit the passenger astronaut to use the thrusters on the MMU for controlling the motion of randomly moving satellites and to tow them back to the Shuttle for repair or return to earth.

The concept of the MMU and its systems, along with the operational plans and developed capabilities, was reviewed by an Aerospace Safety Advisory Panel member at the contractor's plant (Martin-Marietta in Denver, Colorado). In addition, the simulator work, the facility, and the training program were also described and shown. Simulator training was assessed along with methods for coupling the astronaut to the Solar Maximum Mission (SMM) satellite. Similarly, the adapter hardware and procedure for attaching the MMU to the payload bay wall was viewed as part of the total description of how the "space-suited" astronaut

37

mounted the vehicle, detached it from the payload bay wall and reattached it once the mission was completed.

From this individual but thorough review, the Panel notes:

a. The concepts of redundancy for critical systems are consistent, the systems are simple and sufficiently exposed to permit thorough inspection.

b. The cold gas thrust and attitude control system is susceptible to pre-use inspection prior to disengagement from the Shuttle bay wall.

c. The gauge indicating energy available to the thrusters was in a poor position for visual monitoring while the astronaut was secured in the unit's seat. It seemed feasible to move this gauge without destroying the integrity of the systems tests that have been run.

d. The training program has been developed pragmatically along with the unit and appears to be effective. After the first experimental flight with the MMU this program and the formal documentation should be reviewed again by the Aerospace Safety Advisory Panel.

e. It was determined that no "safety" umbilical (tether) is to be used for the first experimental flights and is not contemplated for ultimate operatioanl use. This appeared to introduce unnecessary risk, but the astronaut trainer-director for the program explained that umbilical tangling and snagging represented a hazard judged to be equally severe and that the thruster system of the MMU did not have enough

capacity, even if stuck in "full thrust", to move the passenger out of range of the Shuttle capability for astronaut rescue. Additionally, the "buddy system" provides that a second astronaut in the regular EVA suit will be there.

Based on discussions at the MMU Critical Design Review held November 1983 an additional comment can be made: If, for any reason, there are significant amounts of dust/debris in the payload bay during ground or flight operations, care should be exercised to prevent MMU pneumatic systems from being contaminated which might adversely affect their operation.

LOGISTICS, MAINTENANCE, SPARES AND OPERATIONS

This discussion is based on three specific activities: (1) General Abrahamson's meeting at Kennedy Space Center in November 1982, (2) attendance at a logistics telecon at Rockwell International, Downey, California, in April 1983, (3) visit to Vandenberg Air Force Base in October 1983. In addition, major events have occurred during 1983 which have direct bearing upon the subject:

a. Creation of the Integrated Logistics Panel (ILP) and commencement of working liaison with Vandenberg AFB. This is noted in a Program Directive, SSPM No. 85A issued by JSC's NSTS Office, March 25, 1983.

b. Issuance of an Integrated Logistics Support Policy (ILSP) for the National Space Transportation System establishing a platform for (a) above.

c. The award to Lockheed of the Space Shuttle Processing Contract (SPC).

The meeting at Kennedy Space Center convened by Gen. Abrahamson on November 9, 1982 was the catalyst for the more vigorous logistics, maintenance and support activities which have gradually evolved during 1983.

The Integrated Logistics Support Policy is commendably detailed with seven appendices: Management policy, spares policy, maintenance and repair policy, logistics support functions policy, ILS milestones, ILS definitions and ILS top level documentation tree. It would appear that a number of management level people in both NASA and USAF are looking to the establishment of the Lockheed-managed SPC as a partial answer to

many logistics problems but, although the ILSP was produced concurrently with the contractor-selection award process, the directive does not cite an SPC role in this arena. It is too early to be able to gauge the effect of the SPC program upon logistics but clearly it must necessarily be heavily involved, at both KSC and VAFB.

With respect to the scope of the ILP task, there is concern that it does not include logistics for the Spacelab, Centaur, IUS and PAM elements. It certainly appears that only a complete system ILS program, that is, including the vital payload elements, would have the desirable result of ensuring that the vehicle launch dates can be met from the support viewpoint.

The issue raised by the Aerospace Safety Advisory Panel in earlier annual reports, namely, that of providing logistics control by a single entity appears to remain for the future. The cooperation and growing cohesion of the USAF-Vandenberg and the NASA-JSC/KSC elements is very encouraging but the co-chairing arrangements of the ILP, necessary as they may be at present, do not make for efficient operation in trying to recover some of the critical time lost over the past three years.

The task of the ILP is greatly complicated by the necessity of trying to match the USAF well-developed organizational and management systems with the equally well-established "three-level" system at NASA. This results in a number of organizational "wiring diagrams," interface and procedural documents, few of which, at this writing appear to be completed.

While the issues of supply of components at the line replaceable units (LRU) level appear to be documented and understood some of the necessary suppliers may not be funded. Progress is most certainly being made in detail components but major units such as the SSME with its critical sub-assemblies still are in need of a good, clearly established master plan.

There is also the logistics aspects of transporting the SRB
segments to VAFB which are in need of reinforcement for which the
case for a third set of rail cars is being made.

Storage space at KSC for SRB segments is limited (although
VAFB seems to be better off in this respect) and there is clearly
a need for a study involving a "transportation model" to resolve
some of these issues before they become a trans-continental
transport crisis. In this general context the critical
dependency upon only one B-747 Shuttle ferry vehicle for
coast-to-coast movement should be re-examined.

Based upon our observed development of the logistics spectrum
over the past year it appears that:

a. Considerable progress has been made in trying to
    gain control of the logistics problem.
    Improvements in NASA's interest and organization
    for Integrated Logistics System and sincere
    cooperation and coordination by USAF for the
    projected VAFB operations are certainly showing
    results.

b. There still appears to be issues associated with
    who has the responsibility for Orbiter, that is to
    say between the USAF and NASA. (The Directive says
    that the Air Force has responsibility for it
    "on-orbit." This needs clarification.)

c. The "reporting to" functions of the Integrated
    Logistics Panel (ILP) are still unclear. Should,
    for example, the ILP report directly to the
    National Space Transportation System Program
    Office? Should the ILP functions also embrace
    logistics aspects of operation and launch instead
    of being limited as at present to supply and

42

support tasks? The charter of the ILP, in spite of well-written directives from NASA Headquarters and Johnson Space Center is still unclear.

d.   Considerable worry has been voiced throughout the year about the lack of ILP access to the Spacelab, Centaur, Inerital Upper Stage, and Payload Assist Module systems and the question therefore arises: is the ILP intended only to support Shuttle and not the broad spectrum of NSTS which would include these payloads?

e.   The USAF view seems to be that they can't see anything in the NASA system at present which could be recognized as a well-developed maintenance, supply and logistics curriculum such as the USAF have developed and refined over the years. On the other hand, it appears that the evolving NASA logistics programs are more suited to the special problems of the small Orbiter fleet than the highly-structured, large fleet concepts of the USAF. Providing a workable accommodation between these two opposing philosophies would seem to be a pre-requisite for the ILP but it must be empowered by directive to be able to bring about such a foundation.

f.   The "co-chairing" of the ILP by USAF and NASA is clearly the only arrangement which could be employed at this stage. Perhaps it is too early to establish the function of an overall "czar" of logistics but the difficulties which are beginning to show up from this rather too democratic co-chairing process could probably be short-circuited by the early appointment of a strong top chief with total authority.

g.   The role of the SPC in the entire scheme of things
     needs to be determined and made visible to all
     concerned as soon as possible if some of the
     program's aspirations are to be realized.

Appendix 6

SPACE TRANSPORTATION SYSTEM ELEMENTS

Orbiter Landing Speed and Pitch Control

The Aerospace Safety Advisory Panel has, in the past, called attention to major deficiences in handling qualities of the Orbiter. These deficiencies are well known, highlighted by substantial pitch gyrations during the Approach and Landing Test No. 5 and some subsequent landings. Such control perturbations have been examined by analysis and numerous simulator control explorations. The Aerospace Safety Advisory Panel believes that NASA top management should direct further exploration of the significant benefits to be gained by major changes to improve the pitch control of the Orbiter.

The latest information that the ASAP has found on this problem is a report of the flight control system testing done on the Ames Vertical Motion Simulator (VMS), entitled: "Evaluation of the Space Shuttle Approach and Landing Flight Control System Handling Qualities" by S. D. Griggs, R. J. Grabe, and S. R. Nagel. This study, carefully conducted over a period of several months, by competent engineers and pilots with extensive experience in high performance airplanes and Shuttle simulations, resulted in the following recommendations:

a. Do not replace the current Flight Control System with any of the alternate systems evaluated. Some were found to be slightly better, but not to the extent that a change to the baseline system is warranted.

b. Investigate the feasibility of improving the low speed handling qualities of the Orbiter through airframe modifications, such as the addition of canard surfaces.

Eight different flight control systems were evaluated including software modifications to filters, gains, feedback paths, senor, etc. Ten pilots flew approaches to runways simulating Dakar, Kennedy Space Center, and Edwards Air Force Base. Disturbances were introduced during the approaches to stimulate transients in sensor data, such as changes in radar altitude, in azimuth from the microwave landing system, head/tail winds, and reduced visibility return as in a breakout from low cloud deck. The Heads Up Display (HUD) was not used.

The results show substantial variations in touchdown point, airspeed at touchdown, and vertical speed at touchdown ($\dot{h}$). Different software "improvements" failed to show significant changes; -- and there were a number of "crashes". A "crash" is defined as landing short or long or left or right or with $\dot{h}$ greater than 10 fps.

Pilot comments on the baseline system were:

"Easy to balloon under stress"
"If aircraft disturbed, end up hunting for ground"
"Cannot control aircraft precisely near ground"
"Lag between rotational hand controller (RHC) and vehicle response causes over control for large inputs and undercontrol for small inputs."

These comments on the performance of the recommended system indicate that there is a basic pitch control problem in the aerodynamic design of the Orbiter.

It appears that the attempt to combine pitch and roll control with lift augmentation by the use of elevons on a delta wing

46

results in compromises that have penalized both pitch control and lift augmentation.

The pitch control problem arises from the fact that, on the landing flare, to reduce airspeed, the pitch up moment is accomplished on the Orbiter by raising the elevons which inherently decreases lift coefficient with loss of lift, increasing the landing speed. The loss of lift is in response to a control motion that a pilot normally uses to raise the nose and increase lift! In addition, the inertia of the Orbiter is such that the motion of the c.g. lags the control input by as much as two seconds. The lag and apparent lift reversal can induce over control, and, in some cases, severe pilot induced oscillation (PIO).

The use of canard surfaces to provide pitch control would free the elevons to be used for lift augmentation and roll control. The elevons would have to be limited in droop to maintain adequate roll power but in spite of this, the available increase in lift would be most significant. Estimating from a nominal landing speed of 175 knots, angle of attack of 10°, elevon angle of 0_o, produces an apparent lift coefficient of 0.41. Using the elevons as landing flaps with a canard trimmer might produce double this lift coefficient with a possible landing speed of 125 knots.

The above increase in lift coefficient is not impractical. The advantages of such a landing velocity reduction are very significant from a _safety_ viewpoint:

a. Stresses on wheels and brakes are reduced
b. The risks of landing at Dakar or other short fields are reduced, opening up many alternate abort sites
c. In the event of ditching in the open sea, the probability of survival would be greatly enhanced.

47

One of the significant findings in the Ames Vertical Motion simulator tests was an appreciation of the dangers of attempting a high-weight low-speed landing (like an abort to Dakar). If the angle of attack is increased much above 10°, in an attempt to land slowly, the aerodynamic condition is one of "backside of the L/D curve" where the induced drag rapidly decelerates the Orbiter and increases the sink speed.

In addition to the safety aspects of low landing speeds, the avoidance of pilot induced oscillation must be emphasized. To the non-pilot, the term "pilot induced oscillation" is just that: a disturbance that is felt to be controllable and transient. To the pilots who have experienced it, including the astronauts, it is recognized as a potentially uncontrollable instability. The lack of a landing incident to date is a tribute to the skills of the astronauts, and to the carefully planned and executed training program in high performance aircraft, the Shuttle Training Aircraft, and simulators.

Space Shuttle Main Engine

The current year began unauspiciously for the Space Shuttle Main Engine (SSME) with the discovery of leaks in the STS-6 engines and the resultant delays in scheduled flights. There were a number of intensive reviews of the problems and their systems and management implications. Panel members participated in several of these reviews. Corrective actions were devised and implemented. Subsequently, the engines performed essentially as predicted in all the flights this year. During the STS-8 flight an Augmented Spark Igniter line failed during the shutdown sequence. This had no effect on the mission. The cause of this failure has been identified and corrective action implemented.

Because of the very limited life (one or two flights) demonstrated by the turbomachinery during the FPL (109%) certification test program and in the absence of near-term

flights requiring that thrust level, it was decided to limit planned flights to 104% thrust. Such "derating" is a prudent step. Not only does it provide added operating margin for the SSME, it also should result in longer useable life for the turbomachinery. This should mitigate the logistical problems that would be caused by the need for frequent change-out of turbopumps that are operated at 109%.

The SSME project has embarked on a three-phase program to achieve a long-lived, reliable full power load (FPL) engine. The first phase involves conducting certification extension tests at 104% to obtain more data on durability at that thrust level. The second phase comprises the orderly development, certification and incorporation of a set of design-detail modifications aimed at solving some of the problems encountered with the current FPL design. The third phase includes major redesign changes. Among them are: Redesign of the Hot Gas Manifold to eliminate non-uniform flows and accompanying parasitic pressure losses; elimination of injector baffles and shields, and increasing the throat diameter of the nozzle. All of these changes will tend to "unload" the turbomachinery thus providing greater operating margins and, hopefully, extended useful life. Also included in the plan are steps to provide new turbopump designs should the preceding not prove effective.

The Panel supports this organized approach to solving the problems of the SSME. Such a program is necessary to provide a reliable engine for higher-power operation and to reduce the logistic burden of frequent component removals.

The Panel would like to emphasize that it is important to set the objectives of this improvement program in terms of demonstrated margins of stresses, temperatures, loads, etc., rather than primarily in terms of time at a given thrust level. Stipulating margins gives recognition to the fact that time-to-failure curves are extremely sensitive to stress,

49

temperature, etc., in the vicinity of the ultimate stress limits of materials. This is especially true when materials are operated at the high temperatures that prevail in the SSME.

Having demonstrated such improved margins by, among other things, operating the engine at thrust levels above 109% it is of utmost importance to not fall into the trap of considering the engine to be "rated" for operation at the higher thrust level. What has been accomplished is to have demonstrated that there is a margin for operation at 109%. To operate at the highest level tested would be, in essence, to operate without margin.

The Panel will continue to monitor the progress in the program during the coming year.

Orbiter Structural Integrity

The Orbiter structure was designed to loads that have acquired the name "ASKA 5.1." A later set of loads (now called "ASKA 5.4"), based on revised aerodynamic and thermodynamic data, was used for the most current structural assessment. Flight data analyzed to date (strain gage readings recorded on flights STS-1 through STS-5) have not shown reasonable agreement with predicted strain for the same locations using ASKA 5.4 loads. Even though these initial flights were designed to be as benign as possible, the ASKA 5.4 predicted limit strain on the wing alone was exceeded in:
  a. 63 instances during ascent
  b. 41 instances during descent

Fortunately, there were no instances where the measured strain exceeded a safe allowable limit strain. The numerous exceedances of ASKA 5.4 predicted limit strains without exceeding safe limit strains could be due to:

50

a.   the ASKA 5.1 loads that were used for <u>design</u> were
     more severe than the ASKA 5.4 used for <u>assessment</u>
     in the areas where exceedances were measured

b.   larger than minimum margins of safety were accepted
     and used in the design.

Since flight development was officially concluded with STS-5,
the development flight instrumentation installed in OV-102 has
essentially been dismantled.   There does not seem to be an
adequate plan to acquire the in-flight data required to close out
the discrepancies between flight and analysis data.   Therefore,
the following steps should be taken:

a.   Vehicle OV-102, which was the most densely
     instrumented vehicle, should have all DFI
     (Development Flight Instrumentation) gages
     reactivated and duplicated on both sides of the
     vehicle and should have adequate pressure
     measurements added in order to establish a more
     complete data base.

b.   The initial flights were designed to be as benign
     as possible.   With the flight envelope being
     expanded with each flight, instrumentation should
     be required on <u>all</u> vehicles in order to safely
     monitor future flights.

The failure of flight data to validate the current best
predictions of structural loads raises serious questions about
how the full strength of the Orbiter vehicles can be safely
exploited.   The Panel views the present situation as follows:

a.   ASKA 5.4 loads apparently do not have the correct
     distribution of aerodynamic forces in the ascent
     configuration.

b. Current analytical prediction of internal loads and
    identification of the most critical elements for
    structural failures are not valid.

c. OV-103, OV-104 and OV-105 wing structure will be
    more critical than earlier vehicles because of the
    800 pounds of structural weight removed in a weight
    reduction program. The reduction was based on
    adhering to close margins on ASKA 5.4 loads which,
    in some areas, were less than the ASKA 5.1 loads
    used for the original design. Thus, the failure to
    validate the ASKA 5.4 loads has particular
    significance for these later vehicles.

d. Future plans include missions that can experience
    11% more dynamic pressure (Q) on ascent and 60%
    higher heating rate on descent than has occurred on
    STS-1 through STS-5. The best way to prepare to
    safely fly the most severe mission should be
    addressed.

Vehicle 6.0 Loads/Stress Analysis

Since the time that the ASKA 5.4 loads were derived (in
1976/1977), both flight and wind tunnel data have been developed
that should provide a better basis for generating loads that more
closely represent those being experienced by the full-scale
flight vehicles. It has been proposed that a new set of loads be
derived and used with an updated finite element model to provide
a basis for establishing safe structural limits for future
flights. This proposed effort has been called the 6.0 Vehicle
Loads/Stress Analysis.

The vehicle 6.0 loads/stress analysis would consist of a
complete update of the dynamic, thermal and mechanical loads math
models that takes into consideration all structural configuration

52

changes resulting from the OV-103 weight saving efforts and other
Shuttle element (ET and SRB) modifications. The followng should
also be re-evaluated: aeroheating and thermal gradients,
aerodynamic and compartment venting pressure loads, weight
distributions, inertia loads, ascent trajectories, and the
effects of the redesigned landing gear metering pin. These
efforts should be coordinated with the latest wind tunnel and
flight test data results in order to establish a new internal
loads data base for ascent, descent, and landing conditions.
These loads would then be used as a basis for a new stress
analysis to establish the operational capability of the vehicle.

The Aerospace Safety Advisory Panel believes that another
round of loads analysis of the 6.0 type is necessary in order to
safely utilize the full potential of the Orbiter structure.

Filament Wound Case (FWC) For Solid Rocket Boosters

Results of a full-scale hydrotest of two segments of the FWC
were reported at the Technical Interchange Meeting at Morton
Thiokol, Wasatch Division, on November 16-17, 1983. Full-scale
test specimens TFS 2 and TFS 3 were pinned together with proper
end closures and external tank/solid rocket booster interfaces
and successfully completed hydrotesting on October 21. The test
results are as follows:

> a. The test ran four maximum expected operating
> pressure (MEOP) cycles to 1050 psi with a final
> test to 1478 psi without burst.

> b. The fiber strength in TFS 3 was demonstrated to 442
> KSI.

c.   The factors of safety (F.S) were shown to be:

1.50 Factor of Safety in the membrane for TFS 3
1.42 Factor of Safety in the membrane for TFS 2
1.32 Joint Factor of Safety for All Joints

d.   The test specimens show no signs of delamination or wear.

e.   All test objectives were met.

Two more full-scale specimens are scheduled to be hydrotested to 140% of maximum expected operating pressure by the middle of January 1984. These tests if as successful as the tests of TFS 2/3, will provide adequate certification of the FWC structural design.

Lightweight External Tank

In last year's annual report the Aerospace Safety Advisory Panel recommended that a nonlinear buckling analysis be performed on the Lightweight External Tank (LWT) structure in the area of the LH_2 tank where maximum compressive stresses are produced by thrust from the Orbiter. This analysis has now been completed by Martin-Michoud, and the method and assumptions have been reviewed and approved by an independent consultant, Mr. David Bushnell, of Lockheed Missiles and Space Company. The results show the LWT to have a 60% margin of safety in compression above the design ultimate load. This will add to the 26.5% margin of safety between the design ultimate load and the design limit load. With these analytical results in mind, the Panel is satisfied the LWT is structurally stable for 109% of SSM rated power level.

Landing Gear Design

For many years the ASAP has been pointing out the
inconsistency of the landing gear design loads where the Orbiter
has departed from commercial design practice. Normal commercial
transport aircraft have built-in margins for the maximum loads
expected in landing and braked roll-out conditions since the
critical loads are normally refused take-off with braking and a
1/2g turn. Thus comparison with transports show:

	DC-9	L-1011	Orbiter
Max design load equals max stress (% max stress)	100%	100%	--
Braked roll-out (% max stress)	73%	58%	100%
Touchdown at 10ft/sec (% max stress)	71%	34%	--
5ft/sec (% max stress)	--	--	100%
Static load (% max stress)	48.4%	21%	38.7%
Tire deflection (max Ldg Load)	33%	--	66%

In spite of the fact that brake energy (design) has been
based on abort landings at 240,000 lbs. there have been actual or
incipient brake failures on almost every landing even though
landing weights have not yet approached the design maximum valve.
A review of the brake energy utilized through STS-5 shows that
the pilots have been demanding ever increasing energy. STS-5
used an average of 35.54 millions of foot pounds with a maximum
on one wheel of 42.62 millions of foot pounds. This value
compares to the maximum energy for emergency use of 55 million
foot-pounds and a fuse setting of 42 million foot-pounds,
illustrating the marginal capacity of the brakes.

It has been noted by Robert Rothi that the brake pedals require a 75 # force to achieve maximum brake pressure of 1500 psi. This apparently is extremely difficult for the pilot to do consistently because of the long, tiring mission and not applying full force lengthens the stopping distance appreciably. Here is a PRIME situation to incorporate an "autobrake" system. Autobrakes are currently in production use on the 747, DC-10, DC-9, and other airplanes and the systems have been well-developed. Adaptation for use on the Shuttle should be a simple process and would relieve crew workload and result in shorter, consistent stopping distances.

The brakes were initially designed for 3000 psi, but the torque from the carbon-carbon rubbing surfaces peaked so high near the end of the stop on dynamometer tests that B. F. Goodrich, the brake supplier, was afraid of structurally failing the stators and rotors. Hence, the addition of reducers and the reduction of maximum brake pressure to 1500 psi to limit the peak torque.

Repeating again some of the Aerospace Safety Advisory Panel recommendations, it is suggested that NASA:

    a.   Seriously study the use of a longer nose gear strut or the installation of an expanding nose gear strut to relieve the roll-out loads in landing,

    b.   Similarly study the feasibility of a 4-wheel truck main gear.

Short of such a major change there are a number of less extensive improvements that NASA should seriously address including:

    a.   Place the Shuttle main gear tires on a flat surface on individual load cells at the end of a mission

and record variation in load distribution across the Shuttle. It appears that structural deflections on landing must tilt the shock struts outward loading up the inboard tires to higher loads and causing those brakes to absorb more than their proper share of the energies.

b.   Move the main tire centerline inward toward the shock strut about one inch and increase the tire size as much as the diametral clearances will allow, maybe H46x17-22, or bigger, with a 5° bead seat.

c.   With the larger tire and internal wheel space redesign the brake for greater energy and torque capacity using structural carbon. Support the brake on the axle near the inboard bearing to minimize axle bending.

APPENDIX 7

PANEL ACTIVITIES FOR CY 1983

As in previous years, Panel fact-finding sessions have been
conducted on the average of four times per month for 1983.
Members and consultants have during this same period visited
seven NASA centers and facilities (Ames Research Center, Dryden
Flight Research Center, Langley Research Center, Lewis Research
Center, Johnson Space Center, Marshall Space Flight Center,
Kennedy Space Center) as well as NASA Headquarters, and numerous
NASA contractors. Although these have been focused on the Space
Transportation System, there have been a number of fact-finding
visits aimed at reviewing and assessing aeronautical operations
and attendant flight safety. The Panel has, where practical,
participated in a number of significant in-house reviews; e.g.,
Flight Readiness Reviews, various project hardware/software
technical meetings, STS Support Activities. Panel efforts have
been supported by the Panel Staff Director through in-depth and
continuous participation and reviewing of STS and other
program/project activities as well as aeronautical R&D and
administrative flight safety activities.

The breadth of Panel personal discussions goes from the NASA
Administrator and Deputy Administrator to Program Directors on
into the subsystem design and test personnel (the "hands-on"
people). Beyond this is the Panel's annual report provided to
the NASA Administrator, informal meetings with Congressional
staffs, and testimony before the appropriate House and Senate
subcommittees in January-March period. Where requested, the
Panel provides individual support to special review teams such as
those looking at the Filament Wound Case for the Solid Rocket
Motor, Centaur/Shuttle Safety, and the Shuttle Main Engine
Assessment Group.

SUBJECT: Panel Fact-Finding Sessions Calendar year 1983

Date	Location	Attendance/Subject
1/28-29/83	KSC	STS-6 Flight Readiness Firing (Elverum/Grier)
2/4/83	Rocketdyne Div.	STS-6 Flight Readiness Firing (Elverum/Grier)
2/8/83	NASA HQ	Annual Meeting, 1982 Activities (Panel)
2/22/83	Hercules Corp.	SRM Filament Wound Case (Hedrick/Rothi)
3/2/83	Congress, DC	Panel Testimony to House of Representatives
3/3/83	KSC	STS-6 Flight Readiness Review (Battin/Grier)
3/16-17/83	KSC	Launch Processing Software/Hardware (Battin)
3/30/83	JSC	STS Program Management/Mission Ops (Hawkins/Grier)
4/4-8/83	JSC	Mission ops, aircraft safety, logistics for STS, Logistics Panel, Space Medicine (Parmet/Davis)
4/6/83	Rockwell, CA	Integrated Logistics Panel, Orbiter (McDonald)
4/14-15/83	General Dynamcis	Shuttle/Centaur Level II Reviews (Hawkins/Grier)
4/19-20/83	MSFC	STS Projects (SSME, ET, SRB), Spacelab, Space Telescope, Filament Wound Case (Panel)

4/21/83	NASA HQ	STS Logistics Programs/Policy (McDonald)
4/27-30/83	Rockwell, CA	Space Shuttle Main Engine/Orbiter (Himmel)
5/25-26/83	NASA HQ	TDRSS Ops, Orbital Communications (Battin/Davis)
5/31-6/1/83	JSC	STS Autoland, Flight Trajectories (Battin)
6/1-2/83	JSC	STS Autoland, RTLS abort, Crew Support (Davis)
6/2-3/83	JSC	Spacelab Safety Review (Parmet)
6/8-9/83	Hercules Corp	Filament Wound Case Status/Problems (Hedrick/Rothi)
6/10/83	NASA HQ	STS-7 Flight Readiness Review (Himmel)
6/14-16/83	KSC	Special SSME Management Review Team (Himmel)
6/27-30/83	ARC	Aviation Safety Inspection Review Autoland Simulator operation (Davis)
7/12-13/83	General Dynamics	STS/Centaur Integration and Ops (Panel)
7/14/83	Rocketdyne Div	Space Shuttle Main Engine (Elverum/Himmel)
7/25-28/83	LaRC	Aircraft operational safety (Davis)
8/11-14/83	JSC	Orbital Refueling Test Program (Parmet)
8/23-24/83	MSFC	Technical Interchange Meeting, FWC (Hedrick)
9/14/83	Martin Marietta,	Manned Maneuvering Unit (Hawkins)

9/13-15/83	NASA HQ	Intercenter Aircraft Operations Panel and NASA Aircraft Operations (Parmet/Davis)
9/28-30/83	KSC	Launch Preparations, Shuttle Processing Contractor transition, Aircraft Ops (Panel)
10/7/83	JSC	STS-1 to -8 Biomedical Symposium (Parmet)
10/18-19/83	JSC	Shuttle/Centaur Fluid Systems Safety Review RTG power supply cooling/control (Elverum)
10/19-20/83	MSFC	Filament Wound Case Technical Interchange Review/Meeting (Rothi)
10/19-20/83	VAFB	Integrated Logistics Panel for STS (McDonald)
10/18/83	Congress, DC	Informal meetings with Senate Staff (Hawkins/Grier)
11/8-10/83	JSC	Manned Maneuvering Unit Critical Design Review Orbiter Brakes, Crew Operations (Rothi/Davis)
11/10/83	MSFC	SSME, ET, SRB Production Quality Readiness Review with contractors/government (Grier)
11/16/83	JSC	Orbital Refueling System Safety Review (Parmet)
11/18/83	Brooks AFB, TX	EVA medical status and testing (Parmet)
11/18/83	NASA HQ	STS-9 Flight Readiness Review (Himmel)

61

11/30/83	Rocketdyne, Div	SSME 109% Rated Power Level Status (Hawkins/Grier)
12/2/83	KSC	Shuttle Processing Contractor's Status (Stewart)
12/6/83	NASA HQ	Orbital Maneuvering Vehicle, Transfer Orbit Stage, Tethered Satellite and its operations, Inertial Upper Stage status, activities review (Panel)
12/13/83	Nat'l Res Council	Filament Wound Case Special Committee Meeting (Roth)
12/16/83	LeRC	Centaur Critical Design Review (Himmel)

PLANS FOR 1984

Panel Membership

A number of Panel membership changes are taking place at this time occasioned by events in late 1983. As noted in the front of this report, Robert D. Rothi's passing requires the selection of a new member. Lt. General Leighton I. Davis completed his membership term and has been retained as a consultant to the Aerospace Safety Advisory Panel. Bob Rothi had taken General Davis' position on the Panel. As a result of the selection of the contractor team which included Lockheed and Grumman to perform Space Shuttle Launch and Landing processing at Kennedy Space Center and Vandenberg Air Force Base both Willis M. Hawkins and Ira Grant Hedrick have retired from the Panel. They are remaining with the Panel in a phase-over period to accomplish a smooth transition to new members recently appointed in their stead.

Mr. John C. Brizendine former President of the Douglas Aircraft Company, now an aerospace consultant, has been selected to succeed Willis Hawkins as the new Chairman of the Aerospace Safety Advisory Panel. A brief resume follows:

> John Brizendine completed 33 years with the Douglas Aircraft Company in May 1983 after trying his hand at teaching at the University of Kansas after college graduation. His career included flight test work on a series of high performance research and development, military and commercial aircraft. This culminated in his promotion to Executive Vice President and then President of Douglas Aircraft Company in 1973. John served in the Navy as a Naval Aviator with single and mulit-engine ratings.

Mr. Charles J. Donlan has been selected to fill the vacancy left by Grant Hedrick. A brief resume follows:

> Charles Donlan had 37 years experience in research and development activities with NASA and its predecessor NACA before retiring in 1976. Most of this time was spent at Langley Research Center with the last 8 years spent at NASA Headquarters. Since leaving NASA he has been a consultant to the Institute for Defense Analysis with emphasis on assessing and making recommendations to the DoD on the development of facilities for the space Shuttle operations. His NASA/NACA experience included high speed research aircraft programs and direct involvement with all aspects of manned space flight since the beginning of such programs.

The selection of a candidate to fill the remaining membership position will be made in the very near future.

Panel Activities in 1984

Plans are to continue to focus on a number of aspects of the Space Transportation System as it approaches full operational status, assess the safety implications of upper stages and payloads that interface with the STS and to monitor the safety procedures and practices of NASA's aircraft operations.

Efforts will include at least the following areas of interest and concern:

    o   Shuttle Processing Contractor progress

    o   STS logistics and associated operational
         implementation

64

- Orbiter
- SSME
- Solid Rocket Boosters
- External Tank
- Launch Processing System at KSC and VAFB

o Vandenberg Air Force Base operations and relationships with KSC

o Upper stages including the Inertial Upper Stage, Centaur, Transfer Orbit Stage, Orbital Maneuvering System

o Filament Wound Case for the STS Solid Rocket Motor

o Payloads and on-board experiments and their integration into the STS, for example:

- Refueling Experiment
- Spacelab
- Tethered Satellite System
- Galileo
- Space Telescope

o Extravehicular Activity (EVA) and its support systems including suits, manned maneuvering systems and life sciences

o Rendezvous and proximity operations in space

o The Solar Maximum Mission spacecraft repair flight

o Space Station

o   Certification policy and its implementation
     including product quality and design suitability,
     as well as, use of analyses versus tests

o   Operational procedures to promote safety in the
     STS, space station and other programs

o   Safety of NASA aircraft operations

AEROSPACE SAFETY ADVISORY
PANEL

AEROSPACE SAFETY ADVISORY PANEL

CHAIRMAN

Mr. Willis M. Hawkins (Retiring Chairman)
Senior Advisor Lockheed Aircraft Corporation

Mr. John C. Brizendine (Incoming Chairman)
Formerly President, Douglas Aircraft Company

MEMBERS

Dr. Richard H. Battin
Associate Department Head
Charles Stark Draper Lab. Inc.

Mr. Charles J. Donlan
Formerly, Deputy Associate Adminstrator for
   Manned Space Flight NASA

Mr. Gerard W. Elverum, Jr.
Vice President-General Manager
TRW Space and Technology Group

Mr. Herbert E. Grier
Formerly, Senior Vice President
EG&G Inc.

Mr. Ira Grant Hedrick (Retiring Member)
Presidential Assistant for Corporate Technolgy
Grumman Aerospace Corporation

Mr. John F. McDonald
Formerly, Vice President-Technical
TigerAir, Inc.

Mr. Norman R. Parmet
Formerly, Vice President
Trans World Airlines

Mr. Robert D. Rothi (deceased)
Formerly, Chief Design Engineer
Douglas Aircraft Company

Mr. John G. Stewart
Assistant General Manager
Tennessee Valley Authority

CONSULTANTS

Lt. Gen. Leighton I. Davis
  USAF (Ret.)

Dr. Seymour C. Himmel
Formerly, Associate Director,
Lewis Research Center

EX-OFFICIO MEMBER

Dr. Milton A. Silveria
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Mr. Gilbert L. Roth
Staff Director, Aerospace Safety Advisory Panel

Ms. Susan Webster
Advisory Committee Assistant

ACRONYMS & ABBREVIATIONS

ACRONYMS AND ABBREVIATIONS

AMO	Aircraft Management Office
ASAP	Aerospace Safety Advisory Panel
ASKA	Automatic Systems for Kinematic Analysis
DFI	Development Flight Instrumentation
EVA	Extravehicular Activity
FASCOS	Flight Acceleration Safety Cutoff System
FAMOS	Flight Acceleration Monitor Only System
FRR	Flight Readiness Reviews
FPL	Full Power Level
HUD	Heads Up Display
ILP	Integrated Logistics Panel
IAOP	Intercenter Aircraft Operations Panel
IUS	Inertial Upper Stage
ILS	Integrated Logistics Support
JSC	Johnson Space Center
KSC	Kennedy Space Center
LPS	Launch Processing System
LWT	Light Weight Tank
LRU	Line Replaceable Units
LaRC	Langley Research Center
LeRC	Lewis Research Center
MSFC	Marshall Space Flight Center
MMU	Manned Maneuvering Unit
NACA	National Advisory Committee on Aeronautics
NASA	National Aeronautics and Space Administration
NSTS	National Space Transportation System
OMI	Operations and Maintenance Instructions
OV	Orbiter Vehicle
PAM	Payload Assist Module
PIO	Pilot Induced Oscillation
RPL	Rated Power Level

RHC	Rotational Hand Controller
SMM	Solar Maximum Mission
SPC	Shuttle Processing Contract(or)
SRM	Solid Rocket Motor
SSME	Shuttle System Main Engine
STS	Space Transportation System
TDRSS	Tracking Data Relay Satelite System
USAF	United States Air Force
VAFB	Vandenberg Air Force Base
VMS	Vertical Motion Simulator