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CREWMANS RETENTION SYSTEM

For Protection Against High Speed Ejection up to 600 Knots

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It can be firmly stated that a real-world problem exists in that crewman are being injured and survival equipment is being damaged during high speed ejections.

This Report covers the following areas of work conducted to define, investigate, analyze, and select devices to provide crewman protection

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against the forces of up through a 600 knot open escape seat ejection.

- Definition of the Base Line Conditions and Configurations to be used for aero analysis.
- An update of the data regarding Human Tolerance to Acceleration Forces.
- Establishment of the Design Constraints for the development of a crewman retention system.
- Investigation of Protection Methods
- Investigation of Protection Techniques
- Review of a Martin-Baker MK-GRU7 Type Ejection Seat System's Equipment and Parachute Damage
- Review of a MK-GRU7 Type System's Parachute Characteristics
- The Selection and Substantiation of a Crewman Retention System
- A Discussion of the System's Selected for Improvement of Crewman Protection
- A Discussion of Conclusions and Recommendations

CONTENTS

LIST OF FIGURES

LIST OF TABLES

Section 1

INTRODUCTION/SUMMARY

BACKGROUND

This Program has been sponsored by the Naval Air Systems Command, Code 340B. This Report has been prepared under the Naval Air Development Center's Contract N62269-76-C-0082, under the engineering monitorship of their Crew Systems Department, to fulfill their arguments and objectives that:

> "Crewman's restraint does not adequately protect the occupant during emergency escape through the 600 knot speed range in open ejection seats. With more ejections occurring at the higher air speeds (between 400 - 600 knots), the current equipment and techniques do not provide optimum restraint and protection of crewmembers and their equipment and also degrades system performance. The objective of this program is to establish design requirements, investigate various methods and techniques and develop a system either as an integral system or a combination of systems and techniques to provide increased safety against aerodynamic and deceleration forces through the 600 knot speed range."

DIGEST OF THE REPORT

This Report covers the following areas of work conducted to define, investigate, analyze, and select devices to provide crewman protection against the forces of up through a 600 knot open escape seat ejection:

- Definition of the Base Line Conditions and Configurations to be used for aero analysis
- An update of the data regarding Human Tolerance to Acceleration Forces
- Establishment of the Design Constraints for the development of a Crewman Retention System
- Investigation of Protection Methods
- Investigation of Protection Techniques
- Review of a Martin-Barker MK-GRU7 Type Ejection Seat System's Equipment and Parachute Damage

- Review of a MK-GRU7 Type System's Parachute Characteristics
- The Selection and Substantiation of a Crewman Retention System
- A Discussion of the Systems Selected for Improvement of Crewman Protection
- A Discussion of Conclusions and Recommendations.

PRINCIPAL CONCLUSIONS

The following principle conclusions are made:

- It can be firmly stated that a real-world problem exists in that crewmen are being injured, and survival equipment is being damaged during high speed ejections
- Violent flailing of the crewman's extremities can result in escape system failure
- The Grumman computer programs furnished valid data
- The design constraints developed can be handled by the crewman restraint system concept presented
- Windblast forces are the greatest forces encountered which contribute to direct pressure injury, equipment damage, and flail injury
- Additive rotational acceleration forces can be injurious, whereas linear deceleration forces can be tolerated in a properly stabilized system
- There is no evidence to indicate that there will be thermal injury due to a 1220 P.S.F. ejection
- Ejection velocities of 435 knots and above, substantiated by sled tests, result in more potential damage, and depending on the ejection system will determine the severity of post ejection survival
- A properly ejected, stabilized, decelerated, and parachute recovered crewman ejection system will not exceed the Human Tolerance limits presented
- The following devices were selected to provide additional crewman protection; "Inflatable Support", "Foetal Positioning", "45 Degree Ejection Angle", "Thrust Vector Control", "Afterbody", "Full Face Helmet", "Windscreen", "Modulated Drogue", "Reefing", "Aero-Conical", and the concept of "D.A.R.T." and "Ballistic Spreader"
- The best approach for a Crewman Retention System is considered to be the one that positively positions and restrains the crewman's entire body.

PRINCIPAL RECOMMENDATIONS

The following principle recommendations are made:

- Develop the "Integrated Mission/Survival Garment System" concept to act as a foundation for the integration of all the crewman's necessary survival equipment, clothing, restraint system, and life support systems. This concept will eliminate windblast damage to the crewman and his survival equipment, and unburdern him for improved mission accomplishment

- Develop the "Head, Arm, and Leg Retention System" as being the most positive
- Develop the "Full Face Helmet", "Inflatable Support", and the "Modulated Drogue" concepts to protect against windblast, reduce drag forces, and reduce parachute opening shocks
- Develop and test the feasibility of the aerodynamic "Afterbody" concept for stabilization/deceleration of high $\bar{q}$ escape systems
- Consider "45 Degree Ejection Angle", "Foetal Positioning", "Windscreen", "Reefing", and a new conceptual approach for "D.A.R.T." and "Ballistic Parachute Spreader", as devices for crewman protection
- Continue the development of "Thrust Vector Control", pursue the investigation of the "Aero-Conical" or other parachutes, and review escape systems for incorporation of additional structural support of the crewman
- Consider investigation of the Alternative Approaches to Crewman Retention.

Section 2

DISCUSSION

2.1 BASE LINE CONDITIONS AND CONFIGURATIONS

The following base line conditions and configurations were used for the investigation and development of a crewman's retention system for protection against high speed escape through the 600 knot speed range in open escape seats:

- Martin-Baker MK-GRU7 type ejection seat
  - 480 pounds heaviest ejected weight nominal
  - 9.74 g and 149 g/sec. onset heavy configuration and 12 g and 158 g/sec. onset light configuration catapult performance nominal
  - .250 sec. time, 1200 lb/sec. rocket performance nominal

  (The above information reflects A-6A and F-14A data from the 6 tests used to evaluate equipment deficiencies)
- Light (3,5) and Heavy (95,98) percentile crewmen

  The heavy (95,98) percentile crewmen were chosen for analysis purposes because the resulting windblast/deceleration forces with this man model represent "worst case" conditions for the design of a restraint system, and the larger surface areas will generate larger aerodynamic forces and moments causing a greater effect on seat motion during flailing. The seat bucket position used was for the heavy percentile crewmen (full down), therefore, the largest frontal area was used in the analysis
- Ejection Angle
  - 17 degrees for all configurations
  - 45 degrees for <u>one</u> configuration of crewman ejecting by alternate firing handle between legs
- 600 KEAS at sea level and 45K feet altitude
- 435 KTS, S.L. for correlation of computer program
- Evaluation of dynamic situation through 3 seconds following aircraft separation
- Crewman seated in ejection position with hands at 3 different positions
  - Face curtain fired
  - Alternate handle (between the legs) fired
  - Arms on thighs (command sequence fired)

- Dynamic Situation During Ejection
  - Windblast effect from initial guided travel to prior to influence of drag device
  - Deceleration effect, under influence of drag device
- Crewman, Aero Model Configuration
  - Design data (geometry, weight distribution, C.G., surface areas, C.P. of surfaces) from bioastronautics data book and photographs of anthropomorphic dummy in representative attire at specific configurations
  - Models include C.P. relationship of all surfaces, angle of all surfaces and weight distribution C.G. to an origin which will be the S.R.P. of the seat
  - Each weight model utilizes the following configurations where appropriate

    (1) Hands on face curtain

    (2) Hands on alternate firing handle.

    (3) Hands on top of thighs.

    NOTE: Configurations (1), (2), and (3) represent those where windblast and deceleration forces were calculated.

    (4) Configuration (1), Heavy percentile, with right arm extended horizontally (90 degrees up) and to the side

    (5) Configuration (1), Heavy percentile with right and left arms extended 90 degrees up and to the side

    (6) Configuration (1), Heavy percentile, with right leg rotated 90 degrees outboard

    NOTE: Configurations (4) and (6) represent the critical unsymmetrical arm and leg flailing positions to cause maximum seat instability. Configuration (5) represents a maximum realistic raised center of pressure and C.G. for evaluation of seat motion and deceleration.

    (7) Configuration (1), Heavy percentile with both arms extended horizontally (90 degrees up) and to the side, both legs rotated 90 degrees outboard

    (8) Configuration (7), Light percentile

    NOTE: Configuration (7) and (8) represent the maximum frontal areas of the heaviest and lightest percentile for evaluation of seat motion and deceleration.
- Martin-Baker Seat
  - Design data (geometry, C.G.) F-14 MK-GRU7A seat information.

2.2 DESIGN CONSTRAINTS

This section deals with the establishment of the design constraints for the development of a crewman's retention system for protection against high speed escape through the 600 knot speed range in open escape seats. The section is broken down into four parts that cover:

- Thermal.
- Human Tolerance
- Windblast/Ejection Forces/Deceleration Forces
- Flailing on Seat Performance

Thermal

There is no indication based on ejection history, tests, or theoretical analysis that crewmen will be subjected to thermal injury during a 1220 P.S.F. open seat ejection between sea level and 45K feet.

Figures 13 and 14 plot "Adiabatic Wall Temperature/Mach No/Altitude", and "Mach No./Altitude/Temperature/$\bar{q}$(P.S.F.)" respectively to show what temperatures can be expected if there is a long term exposure. Report No. AMRL-TR-76-2, "The Heat Pulse Associated with Escape From An Aircraft at Supersonic Speed", Reference 5, defines the air-temperature environment and calculates the heat pulse associated with the deceleration of a supersonic ejection. The report compares this information with data on the human body's tolerance to short-period heat pulses to show that thermal injury is not a problem when wearing a full pressure suit and that exposed skin may experience pain above Mach 4 and blistering above Mach 5.

Human Tolerance

Life Sciences participated in this study and took into account omnidirectional open-seat ejection stresses on the crewman. The intent was to initiate an investigation to determine what could be done in the areas of crew restraint and support to permit higher, omni-directional ejection stresses on the crewman. A new look was taken at the aircrew protection fundamentals.

The known and anticipated loads which were imposed were established, human capabilities were investigated, and any materials or concepts that might be applicable were recommended or utilized to develop a system that satisfies the requirements.

No constraints, such as retrofit or designing for a specific current or projected vehicle, were imposed. It was emphasized that the physiological and internal anatomical characteristics of man would be the primary considerations, as opposed to his obvious external configurations.

An update of the literature was conducted in order to assemble into one report information and findings on man's tolerance to 'g' forces. The necessity of this study resulted from the wide differences in the data previously reported and the attempt to standardize the values.

The immediate purpose of the study was to update the acceleration and deceleration data currently used by our Life Sciences personnel and concerned design engineers.

The first input was from our own extensive Life Science and GAC libraries. In addition, a request was made to the New England Research Application Center (NERAC) to conduct a literature search covering the time from 1971 to the present. We had sufficient data in our files which covered the time prior to 1971. An update of the literature gave us plotted curves which represented all the reported data points relating to acceleration and deceleration forces and based on no-injury criteria. In addition to the no-injury criteria which provided the basis for evaluation of actual reported forces, the curves were plots of those data points where the occupant was restrained with a simple restraint system consisting of a lap belt and shoulder harness. No anti-g suit, or any other restraint device data points were plotted.

Once the plots had been placed on the graph paper a computer program was prepared which then provided a "best-fit" curve. This curve was then designated as the "no-injury" curve. Because a number of reported points fell above the line and yet were reported as non-injurious, a second curve was established manually which represented what was designated as the outer limit of a "gray" area or the threshold of injury. What these curves represent is a non-injury zone. Any g-forces above this zone will result in injury or possibly be fatal. This zone is based on actual data points, but in addition a certain amount of extrapolation was included to provide a parallel line to the first. This is based on the fact that acceleration and deceleration tolerances follow a straight line curve when magnitude is plotted against time. These curves are presented in Appendix A and Figures 54, 55, 56, and 57 of this report.

Life Sciences also aided in establishing the surface areas (Tables 1, 2, 3) of the body so as to provide body planes (Figure 19) for the aerodynamicists to calculate the force vectors on the body from wind blast. The purpose was to determine what $\bar{q}$ values are present and on what surface area of the body during high speed ejections.

Once this information was available it would then be within our realm to determine if the arms and legs would have to be restrained and to what extent the other surfaces of the body would have to be protected from this stress.

Anthropometric data concerning the 5 - 95 percentile flying personnel were provided for this purpose. In addition, 3 and 98 percentile data were also made available. The data that was used was taken from a report entitled "Anthropometry of Naval Aviators", NAEC-ACEL-533, dated 1964. In addition to this documented data another reference document was used. This was entitled "Anthropometry in Aircraft Engineering Design". This report provided the formulae for determining body surface areas, hinge points, centers of gravity, and moments of inertia through various portions and/or segments of the body.

In addition to the data provided to the specific groups responsible for this study, contact was made with the Navy Safety Center (Mrs. E. Rice) to compare notes and to discuss the statistical analysis of the data obtained by the Safety Center during high speed ejections. These discussions confirmed the original Grumman premise that the individual must be protected during this ejection stress. Although the design of the escape system is considered satisfactory and functions as required, nature produces an individual which, unless adequately protected, will not be able to survive the mechanical system. Discussions with the Navy Safety Center revealed that fatalities reported through the 600-knot range do not provide sufficient information as to the cause of death due to the fact that in most instances the ejections were over water, and the bodies were not recovered. It must also be emphasized that the system must provide automatic components, including parachute release and flotation capabilities, once the individual impacts the water. Insistence must also be put on arm, leg, and head restraint.

Summary reports of the data discussed with the Navy Safety Center are available and referenced in this report (Reference 8 and 9).

Once the foregoing had been accomplished, Life Sciences participated in the trade-off studies necessary for the selection of a satisfactory restraint system. In addition to these studies, a number of materials and basic concepts for possible solutions to the restraint system were evaluated and recommendations made.

The final step in this effort was to conduct a data evaluation and prepare reports.

The first such report (Appendix A) was entitled "Physiological Tolerance To Acceleration and Deceleration Forces (An Update of the Literature)."

The second report (Appendix B) was entitled "Physiological Aspects of Wind Drag Acceleration".

The third report (Appendix C) is entitled "Review of the Literature, Re: - Wind Blast Effects and Thermal Effects During High Speed Open Seat Ejection".

On the basis of the foregoing, it becomes necessary to state that a great deal of information is available and must be integrated into a design. Emphasis must be placed in the areas of torso garments, seat pan, comfort and intimate fit, head restraint (forward and lateral), arm support and arm rests, hand holds and arm straps, legs and leg positioning, leg back rest and leg cover.

Life Sciences has provided the necessary, pertinent information to the design engineers together with the rationale.

Windblast/Deceleration Forces

A. Aircrewman Model

Three aircrewman configurations were analyzed for windblast and acceleration/deceleration effects during a 600 knot seat ejection:

(1) Hands on face curtain

(2) Hands on alternate firing handle

(3) Hands on thighs.

An example of one configuration, hands on alternate firing handle, is presented, along with its direction designation, in Figure 19. Tables 1, 2 and 3 present the distances to the center of pressures from the seat reference point (S.R.P.) and the angles of each surface about the x-axis for the three configurations. Table 4 presents the distances to the centers of gravity (C.G.) of each body component from the S.R.P. for the three configurations. Also presented are the weights of each body component and the nominal location of the total seat/man C.G. for all three configurations. Table 5 presents the point locations used in the calculation of the restraining forces.

All locations, weights are for the 98 percentile aircrewman. The heavy (95, 98) percentile crewman was chosen for analysis purposes because the resulting windblast/deceleration forces with this man model are representative for the design of a restraint system. The larger surface areas generate larger aerodynamic forces and moments affecting seat motion during ejection. The seat bucket position used for the heavy percentile crewman (full down) is the largest frontal area for the seat/man system. Although the light (5) percentile crewman would be subjected to higher dislodgement forces at drogue inflation because of less deceleration and lower mass, this difference was not considered significant for the purpose of overall restraint system design.

B. Methodology

A Grumman Six-Degree-of-Freedom Trajectory Program, Reference 1, was used to get representative time histories of two ejections:

(1) 600 knot, sea level

(2) M = 2.38, 45,000 feet

both at a dynamic pressure, q_{∞}, of 1220 psf. The program requires the following data to compute these trajectories:

(1) Rocket, catapulting and geometric characteristics of the Martin-Baker MK-GRU7 ejection seat

(2) Aerodynamic data, Figure 45, of a seat/man combination (based on Reference 2)

(3) Aerodynamic deceleration characteristics of the drogue and main parachutes (Reference 3).

Three aircrewman configurations were analyzed:

(1) Hand" on face curtain

(2) Hands on alternate firing Handle

(3) Hands on thighs.

The velocities and accelerations of the seat/man C.G throughout the trajectory time histories are not appreciably altered by differences in aerodynamic data for the three configurations. Therefore, configuration (3) was used as the base condition for the trajectory time histories. In order to substantiate that the computed trajectories represented realistic conditions as to angular rates and loads at the seat/man C.G., a set of sea level 600 knot and 435 knot computed trajectories were correlated with actual sled test ejections at the same speeds. Good general agreement at these two conditions precluded any additional correlation effort.

Auxiliary computer programs were then developed to input the time histories of the accelerations and velocities computed by the six-degree-of-freedom computer program with the aircrewmen characteristics from Tables 1, 2 and 3 to generate windblast/deceleration forces. For the windblast force, at the center of pressure of each surface of the aircrewmen model, the following calculations were made:

(1) The local velocity:

$$U_{C.P.} = U_{S/M} + \Delta Z \cdot q - \Delta Y \cdot r$$

$$V_{C.P.} = V_{S/M} + \Delta X \cdot r - \Delta Z \cdot P$$

$$W_{C.P.} = W_{S/M} + \Delta Y \cdot P - \Delta X \cdot q$$

where, U_i, V_i, W_i = the x, y, z inertial components respectively, of the local velocity at the i^{th} center of pressure of each surface, i varies from 1 to 32 surfaces describing the pitch plane modeling of the aircrewmen

$U_{S/M}$, $V_{S/M}$, $W_{S/M}$ = the x, y, z inertial components, respectively, of the velocity of the seat/man C.G.

$(\Delta X)_i$, $(\Delta Y)_i$, $(\Delta Z)_i$ - the distances, along the x, y, z axes respectively, to the i^{th} center of pressure of each surface from the seat/man C.G.

p, q, r - the roll, ptich, yaw rates respectively, of the seat/man C.G.

(2) Assuming subsonic, incompressible flow, Bernoulli's Equation was applied at each surface to derive an expression for pressure coefficient, C_p, as follows:

$$P_\infty + q_\infty = P + q$$

$$\frac{P - P_\infty}{q_\infty} = 1 - \frac{q}{q_\infty}$$

$$q_\infty = \frac{1}{2}\rho_\infty V_\infty^2$$

$$q = \frac{1}{2}\rho_\infty V_T^2$$

$$C_P = 1 - \frac{V_T^2}{V_\infty^2} = \frac{V_N^2}{V_\infty^2}$$

where

P_∞ = freestream static pressure

P = static pressure of each surface

ρ_∞ = freestream density, constant

V_∞ = local freestream velocity at each surface's center of pressure (U_l, V_l, W_l are the x, y, z velocity components respectively)

V_T = surface tangential velocity

V_N = surface normal velocity

Therefore, the normal windblast force, F_N, at each surface is given by: $F_N = C_P q_\infty A$ where, A is the area of each surface. In order to compute the normal velocity, V_N, and consequently, the pressure coefficient, C_p, an expression for the normal vector to each surface was developed based on the angle θ presented in Tables 1, 2 and 3, the aircrewmen model configurations. The normal vector expression used: $\vec{N} = \sin\theta\,\hat{i} - \cos\theta\,\hat{k}$, and the convention used is depicted in Figure 46. Then, with η, the included angle between the local velocity vector and the local normal vector at each surface, the following can be derived:

$$\cos\eta = \frac{\vec{V_\infty} \cdot \vec{N}}{|\vec{V_\infty}|\,|\vec{N}|}$$

where, $\vec{V} \cdot \vec{N}$ vector scalar product = $U_i \sin \theta - W_i \cos \theta$

$$|\vec{V}_\infty| = \sqrt{U_i^2 + V_i^2 + W_i^2}$$

$$|\vec{N}| = 1.0, \text{ unit vector}$$

When the cos η is less than zero, the surface is shielded from flow impingement. Otherwise, $V_N = V_\infty \cdot N$ and $V_T = \sqrt{V_\infty^2 - V_N^2}$. Therefore, the components of the windblast force at a surface are, in the pitch plane: $F_x = F_N \sin \theta$, $F_z = -F_N \cos \theta$, with the resultant force: $F_R = \sqrt{F_x^2 + F_z^2}$.

The deceleration forces are computed by (1) inputting Table 4, the C.G. locations of each body component, and (2) by calculating the local accelerations at each C.G.:

$$\dot{U}_{CG} = \dot{U}_{S/M} - \Delta X \cdot (q^2 + r^2) + \Delta Y \cdot P \cdot q + \Delta Z \cdot p \cdot r$$

$$\dot{V}_{CG} = \dot{V}_{S/M} + \Delta X \cdot p \cdot q - \Delta Y \cdot (p^2 + r^2) + \Delta Z \cdot q \cdot r$$

$$\dot{W}_{CG} = \dot{W}_{S/M} + \Delta X \cdot p \cdot r + \Delta Y \cdot q \cdot r - \Delta Z (p^2 + q^2)$$

where, $\dot{U}_{C.G.}$, $\dot{V}_{C.G.}$, $\dot{W}_{C.G.}$ = the x, y, z inertial components respectively, of the local acceleration at each body component C.G.

$\dot{U}_{S/M}$, $\dot{V}_{S/M}$, $\dot{W}_{S/M}$ = the x, y, z inertial components respectively, of the acceleration of the seat/man C.G.

ΔX, ΔY, ΔZ = the distances, along the x, y, z axes respectively, to the body component C.G. from the seat/man C.G.

p, q, r = the roll, pitch, yaw rates respectively, of the seat/man C.G.

(3) The forces along the x, y, z axes are then calculated by multiplying the mass of each body component, from Table 4, by the above accelerations of each C.G. The resultant force is then:

$$F_R = \sqrt{F_x^2 + F_y^2 + F_z^2}$$

Restraint forces were calculated to present the design loads a restraint system must anticipate to prevent rotation of the elbow and wrist points about the shoulder, the knee about the hip and the ankle about the knee. First, the maximum separation forces in the x and z directions of the pitch plane were determined. These occur during the time period for drogue parachute deployment, approximately 0.8 to 1.5 seconds after sear-pull. An impulse acting to decelerate the seat/man system over the steady windblast deceleration causes the body components to react in the direction opposite to the pulse. Figure 44 exemplifies the procedure used to determine these forces. Each force presented acts to displace the head, in this example, from the seat. These forces together with the distances to the point locations mentioned above are used in the moment equations that define the restraint forces.

C. Results

Figures 47 and 48 present the time histories of two ejections:

(1) 600 knot, sea level

(2) M = 2.38, 45,000 feet.

These results describe the attitude, angular rates and loads on the C.G. of the seat/man combination. An additional trajectory time history for 435 knot seat ejection, Figure 49, is included since it was used for correlation purposes with the Six-Degree-of-Freedom Trajectory Program. The final trajectory time history presented, Figure 50, is for a 600 knot seat ejection with a two stage drogue. The two stage drogue alleviates the loads on the seat/man C.G.

An example of the total forces, windblast/deceleration, on a body component are presented in Figure 28. The seat attitude and height during the ejection trajectory are also presented. The deceleration force levels from initiation of ejection to deployment of the drogue parachute are a combination of rocket thrust, internal forces as well as windblast. After drogue parachute deployment, the levels then contain the drag of the parachute. A comparison of the deceleration force levels for a body component are shown in Figure 34 for the two ejection cases. The disparity in force levels during the period prior to the drogue parachute deployment is due to the Mach number effects. Figures 47 and 48 demonstrate that the pitch attitude for the 600 knot, sea level ejection decreases quicker than for the M = 2.38, 45,000 feet ejection. This is due to the larger values of pitching moment about the seat/man C.G.

for the M = 2.38 ejection. Consequently, for the 600 knot case, the values of C_x are decreasing, while for the M = 2.38 case, they remain at an already higher level. When the attitude of the M = 2.38 case finally begins decreasing, the values of C_x increase greatly before tapering off, see Figure 45, aerodynamic data of the seat/man combination. Since the values of C_x differ the most during this interval, they account for the differences in force levels at the seat/man C.G. and, consequently, of the acceleration at this point. Therefore, this effect is transmitted to all the body components as demonstrated by Figure 34. Otherwise, the deceleration force levels are comparable and, consequently, the restraint forces were developed for the 600 knot, sea level case.

An example of the windblast force levels are presented in Table 6. A further breakdown, necessary for design purposes, is the maximum pressures, forces, normal and tangential velocities on the individual surfaces of the aircrewmen model; these data are presented in Table 7.

A table of Restraint Forces is presented in Table 8. The maximum values of the component forces are listed, except for two cases:

(1) The x-component of the knee restraint force is assumed absorbed by the seat-torso restraint, and

(2) The z-component force at the ankle is assumed to be absorbed by the knee restraint.

Configurations (2) and (3) are sufficiently close in appearance to have comparable values of restraint force.

Flailing On Seat Performance

Five flailing aircrewmen configurations were selected and their trajectory time histories are presented for comparison to the basic 600 knot, sea level time history, Figure 47.

The configurations are:

- (4) Left hand on face curtain, right arm extended horizontally (90 degrees up) and to the side
- (5) Both arms extended horizontally (90 degrees up) and to the side
- (6) Hands on face curtain, right leg rotated 90 degrees outboard

- (7) Both arms extended horizontally (90 degrees up) and to the side, both legs rotated 90 degrees outboard
- (8) Configuration (7) for the 5 percentile aircrewmen.

Incremental aerodynamic coefficients for the above configuration were developed from Reference 2 assuming the extended limbs were cylindrical in cross section. These coefficients were then added to the data of Figure 45 and used in the Six-Degree-of-Freedom Trajectory Program to produce time histories. Configurations (4) and (6) represent the extremes of limb positioning due to flailing which causes significant out-of-pitch plane motion of the seat. From the trajectories presented, Figure 51 and Figure 53, yaw rates of as much as 500 degrees/second for configuration (4) and 600 degrees/second for configuration (6) were generated during the first 0.4 seconds of the time history. During this period, the axial loads induced by windblast increased due to the increased frontal areas presented by the extended limbs, while the normal loads remained similar to the base non-flailing run. After an initial brief period, it is understood that the ultimate position of the extended limbs would be sufficiently changed to alter the remaining time history. Assuming that the limbs remained in their initial configurations for a period of 0.4 seconds, the large out-of-plane rotations induced would very likely cause drogue and main parachute fouling with the seat.

Configurations (5), (7), and (8) represent extreme flailing configurations which increase the normal and axial loads on the crewman. Since the flailed limbs are symmetrically extended only pitch plane motion develops. Figures 52, 53, and 60 are the trajectory time histories for configurations (5), (7) and (8) respectively. Figure 61 compares the seat/man velocity for configurations 2, 5, 7, and 8. The data shows:

- As the number of limbs of an identical percentile are extended (configuration (5) arms out, (7) arms and legs out) the frontal area increases to induce an increased axial load with a resulting faster deceleration
- A spread eagled 5 percentile (configuration 8) will decelerate faster than a spread eagled 98 percentile (configuration 7) to induce a 5 g increased axial load.

In each of the cases for which flailing trajectories were computed, the deceleration effects from windblast forces increased with the number of limbs projecting into the windstream. Rotational accelerations caused by initial asymmetric projections of limbs into the windstream, induces additional limb flailing and further possible injuries. This effect was not examined in this study since limb positions were assumed fixed throughout the ejection sequence.

2.3 PROTECTION METHODS INVESTIGATED

Some specific methods for optimizing personnel retention for protection during ejections through the 600-knot speed range are discussed below.

Flexible Retention

Positive retention by flexible lines or webbing appears to provide a multi-degree-of-freedom of system concept. Flexible materials are easily adaptable for point attachment, they align with the load vector, are compatible to the variability of the human body, can be adjusted easily, can be wound up or reeled in, are light, can be easily and quickly cut for separation purposes, and come in many materials such as cable, wire, webbing, cord, and plastic. Figures 3, 4, 6, 7, 8 and 9 represent some concepts.

Foam in Place

Techniques for producing instant rigid foam are available in the industry. Foam in place can be very desirable when you consider that it can be configured to provide a protection shield against windblast and aerodynamic heating. It has the disadvantages of requiring a shape controlling system, a reservoir of foaming ingredients, and the inability of being quickly removed from the crewman. The crewman must have instant total mobility to survive the post-ejection rigors of a tree, rock, land or water landing from which he must plan his survival with the equipment he is provided with.

Foam in place has been considered as a device to trap or reposition the torso and thighs relative to the seat, and as a collar to support the head. It has not been considered as a device to retract and hold the crewman's arms and legs, as this rigid concept is not compatible to the flexibility of the number of limb positions, nor is there any practical method of rigidizing the arms at the shoulder to prevent forcible displacement from the torso.

Foam in place does have the advantage that once it is rigidized it will not lose its shape due to damage from puncturing, abrasion, etc.

Inflatables

Inflatable devices can be quickly inflated and deflated as desired. This means that this method of protection is compatible with the requirements of ejection systems and post-ejection survivability. The inflatable concept can be used as a shield against windblast and aerodynamic heating. It is a perfect device for retaining the crewman's head as a rigid extension of his torso. (see figures 3, 4, 8, and 9). It is a perfect device for repositioning portions of the crewman's body that are in contact with rigid support. Leg positioning is shown in Figure 5. It is a perfect device for tightening torso restraint straps by inflating bladders under the straps to create an added pressure on the crewman's body. If these bladders are enlarged, they will act as a large surface area to distribute eyeballs-out deceleration forces, or for that matter, crash forces.

Inflatable concepts have not been considered as a device to retract and restrain the crewman's arms and legs against aerodynamic and acceleration forces since there is no practical method of rigidizing the arms at the shoulder to prevent forcible displacement from the torso.

Encapsulated Seats

Encapsulated seat concepts remain as a long term alternative which will increase weight, cost, system complexity, airframe impact, and crewstation design. Due to these facts it appears that this approach is not the near-term answer for providing additional protection against 600-knot ejection environments.

Rigid Mechanical Restraint

Rigid mechanical restraint, in the form of articulated surfaces and/or bars, has been rejected for the following reasons. It would be very difficult to retract a crewman's arms from any position that they might be in. Percentile accommodation without pre-flight adjustment would be complex. You cannot predict where the crewman will adjust his eye to, and you have to be careful you do not completely restrict body component dynamic shift because this motion to a degree is a built-in damper for body protection.

Larger fixed geometry or articulated seat structure support surfaces can only improve crewman support from displacement; however, crewman mobility in the cockpit must not be restricted and the added complexity of an articulated device is considered to be complex.

Crewman Garments

The use of a crewman's garment to integrate the entire retention device, other than the retraction system, appears to provide a concept which can be integrated with all the crewman's protective and survival items over a wide range of application. Figure 11 is a conceptual configuration for a maximum garment which of course can be simplified depending on the aircraft's specific mission requirements. This garment concept addresses all hostile environments and yet provides the crewman with a retention system that he is basically unaware and unencumbered by.

Foetal Position

Partial foetal positioning of the crewman will cut down on the frontal drag area of the seat (Compare figures 1 and 5) which can only help to reduce the transverse, eyeballs-out, deceleration forces. It also places the legs in a position to partially protect the abdominal area from direct windblast as the crewman exits the aircraft. The crewman's arms become located within the torso's frontal area to give them support against windblast effects and to act as another abdominal protective device.

Reduced frontal drag by foetal positioning theoretically will improve the escape system by permitting the stabilization/deceleration device to be larger and more aerodynamically effective during a zero-zero ejection.

2.4 PROTECTION TECHNIQUES INVESTIGATED

Before discussing the techniques investigated by this program, it is desirable to give a brief description of what is occurring during a 1220 P.S.F. ejection at sea level and 45K feet, with the selected base line Martin-Barker MK-GRU7 type ejection seat.

Windblast forces at aircraft separation constitute the most damaging conditions to an unrestrained crewman. Figures 25, 26, 27, 29, 30, and 33 plot the X and Z axis forces, from aircraft separation thru 3.0 seconds from ejection initiation, for the head, lower leg, upper leg, upper arm, lower arm, and hand respectively. As the seat is free to yaw, we will consider as the worst condition all X axis forces to represents Y axis forces.

Since windblast forces subside as the system decelerates, the only other problems the crewman faces are rotational forces and deceleration forces imparted by the stabilization/deceleration device, which in the selected system for evaluation is a Drogue Chute System.

Rotational forces for body extremities become quite large due to the fact that the seat is searching for its equilibrium position prior to drogue chute control. Figures 28, 32, and 41 provide seat pitch position data in degrees. The data shows that the seat back whips from its initial 17 degree aircraft separation position to a -50 to -60 degree forward pitch position in 0.2 to 0.4 seconds respectively due to aerodynamic forces. The seat then rotates violently back to a 115 to 140 degree aft pitch position in approximately 0.5 seconds due to the influence of drogue chute forces.

Let us look at the effect that altitude, with the resulting Mach Number increase, has on the performance of the Martin-Baker Duplex Drogue System when comparing an equivalent $\bar{q}$ of 1220 P.S.F:

- Figure 39 shows that altitude reduces the peak normal gee from 24 to 14
- Figure 40 shows that altitude reduces drogue drag load from over 9000 pounds to 3000 pounds
- Figure 41 shows that altitude increases the magnitude of seat pitch from -50 to -59 and +118 to +140 degrees.

These effects are the result of the Drogue System being blanked out by the supersonic shock wave off the seat. This blanketing reduces the drag effect, which in turn reduces the normal g, but increases seat pitching.

Figures 21, 22, 23, 29, 30, 33, and 35 plot the X and Z axis acceleration forces, from aircraft separation through 3.0 seconds from ejection initiation, for the head, lower leg, upper leg, upper arm, lower arm, hand, and foot respectively. It can be seen that the maximum forces build up between 0.9 and 1.1 seconds when the seat is whipping backward due to drogue chute inflation. This means that, depending on whether the seat is facing forward or rearward, the unsupported portions of the crewman should be restrained to the seat structure to prevent their displacement and potential flailing.

The techniques to be investigated are those that protect the crewman from initial windblast forces, rotation, and deceleration forces. Some specific techniques that were investigated for optimizing personnel protection during ejections through the 600 knot speed range are discussed below.

Ejection Direction

A comparison was made to see if ejecting in a more aftward direction would provide more protection to the crewman. Figure 17 shows the comparison of a 13 and 45 degree back-angle cockpit ejection configuration. The initial drag area is reduced from 6.0 square feet to 4.9 square feet respectively at the time the seat separates from the aircraft. Note that there will be no discussion in this report on the design of, or the advantages and disadvantages, of an increased back-angle cockpit, as this is not pertinent at this time.

A review of the data presented by Figure 59, (45 degree ejection angle), and Figure 47, (17 degree ejection angle), indicates the following effects brought about by ejecting at a greater rearward direction during a 600 KEAS escppe:

- The seat pitching magnitudes and oscillations are almost identical throughout the entire trajectory except that the most forward pitching position is reached approximately .15 seconds later
- The normal g during the initial rocket boost phase on leaving the aircraft is 15 g, (or 7 g greater than a 17 degree ejection), due to the fact that windblast deceleration forces on the bottom of the seat and the rocket forces are additive.

The results of this data show that there is no advantage gained by ejecting in a more rearward direction with a seat that is not stable in the attitude at which it leaves the aircraft. If the seat were to remain stable at the exit angle of 45 degrees the following potential benefits could be expected due to the reduction of drag area and crewman positioning in the airstream:

- Ejection capabilities beyond 600 KEAS, where the frontal drag area of the upright ejection system begins to create a deceleration force beyond the human tolerance of the crewman
- Better windblast protection of the crewman's torso area due to the blanketing effect of the rigid structure of the lower legs.

Seat Orientation/Stabilization

Even if you had the space and time to rotate the existing type service ejection seats 180 degrees in the pitch or yaw plane, prior to exiting the aircraft, the projected area of these seats are not great enough to blanket the crewman's entire body from initial windblast forces.

Controlled orientation of the seat through the combined seat/man ejection cycle will prevent unnecessary rotational forces to be applied to the crewman and will permit a controlled deceleration stage. Some aerodynamic, mechanical, and powered devices for seat orientation are discussed below.

- Aerodynamic Devices

- Fins, plates, and booms have been tried in the past primarily as a fix and not a solution, otherwise these features would be incorporated in present day ejection seats

- Drogue chutes, when properly bridled and rapidly deployed to prevent the seat from violent aerodynamic trimming, are an effective device to orient seats. The size, type, and method of deployment are tailored to the individual escape system

- An aerodynamic afterbody concept, shown in Figure 10, can conceivably not only provide for seat orientation and stabilization throught the entire seat/man trajectory, but provide a degree of streamlining which could open the door to 2000 P.S.F. open ejection seat escape systems.

Reference (10), "High $\bar{q}$ Open Ejection Seat System, Phase Ic Study", is a report that deals with, and confirms, the feasibility of utilizing an aerodynamic inflatable afterbody for stabilization and deceleration of the high $\bar{q}$ seat system, following a supersonic ejection. The Report substantiates that the inflatable afterbody keeps the stabilization and deceleration forces within human tolerance if ejection occurs at velocities between Mach 1.16 at sea level and Mach 4.1 at 60,000 feet. The approach used in this study was:

- Develop seat/man/afterbody combined center of gravity location
- Develop seat/man/afterbody configurations for aerodynamic analysis
- Conduct aerodynamic analysis of the high $\bar{q}$ seat system.

- Mechanical Devices

- Stencel Aero Engineering's D.A.R.T. (Directional, Automatic, Realignment of Trajectory) system is being used at present as a modification to some Escapac Seats and on their new technology SIIIS seat system. Very simply a braking and bridling system, deployed from the bottom of the seat and attached to the cockpit floor, imparts a force to the seat to counteract any forward or aft pitching of the seat during the initial trajectory phase

- Extending seat guide rails and curved guide rails have been used in the past with very few lasting authoritive benefits derived.

- Thrusting Devices

- STAPAC, a MacDonnell Douglas innovation for initial seat orientation, consists of a vernier rocket motor, rate gyro, gyro spin-up actuator, biasing spring, and interconnecting linkages. The device provides a counter rotating force to that which is pitching the seat forward or aft during ejection seat rocket burning, and then produces an aft pitching rate to accommodate the next phase of the escape system.

- Most ejection seat designers have considered secondary multiple and single thrusting devices for seat orientation at one time or another. Tethered, aft firing rockets have been considered to replace drogue drag forces. "Q" sensing rockets have been mounted on head-rests to counteract conditions of initial aft pitching of a seat. Multiple rockets have been theoretically considered for selective thrusting in the X, Y, Z axis. Thrust vector control of the main seat propulsion rocket is probably the only concept at this time that can economically provide the thrust levels necessary to overcome the enormous aerodynamic forces of a 1220 P.S.F. ejection. Technical report AFFDL-TR-75-105, "Fluidic Thrust Vector Control for the Stabilization of Man/Ejection Seat Systems", Reference 4, describes the preliminary design of a 2-axis, hydrofluidic thrust vector control (TVC) system to improve total trajectory of an ejection seat system during adverse conditions from 0 to 600 knots air speed. It should be noted however, that the TVC system is only effective when thrusting, and the seat/man combination still requires stabilization control at rocket burnout when decelerating from high speed.

Wind Deflectors/Canopy Shielding

In the early days the Air Force experimented with the use of a skip-flow-generator. This was a boom extending forward of the seat. It created a shock wave in front of the seat to protect the crewman when ejecting at supersonic speeds. This concept was never incorporated into service aircraft.

Figure 15 shows the concept of erecting the aircraft's windscreen in such a manner as to generate a reduction of freestream '$\bar{q}$' in the space the seat is ejecting through as it leaves the aircraft. Figure 12 is a simple plot for determining the percent of freestream air reduction and its effective influence behind the windscreen based on the size of the windscreen.

Erecting the aircraft's windscreen protects the crewman by reducing the initial windblast forces on his body; however, the small amount of protection gained during an ejection at a $\bar{q}$ of 1220 P.S.F. does not seem to warrant the increased complexity, cost, and weight that must be incurred. If the articulation and/or removal of the windscreen were to be considered as a standard maintenance procedure for optimum access to equipments, controls, and displays in this area, then a cost effective program would have to be implemented for the particular aircraft involved.

Streamlining

Streamlining an irregular object, like an ejection seat, will allow it to slip thru the air with less drag. This in effect will allow you to present a larger projected frontal drag area during the deceleration phase without increasing the forces on the crewman. Figure 10 represents a concept for streamlining an ejection seat by the use of an aerodynamic afterbody. A discussion of this concept is presented under "Aerodynamic Devices" as a means of seat orientation.

Drogue Drag Modulation

Drogue parachutes are a time honored, conventional, and well established method for stabilizing and decelerating an ejection seat. Many combinations and types, Figure 43, have been experimented with throughout the years, and generally each different escape system requires its own design. We will not discuss the various systems but merely point out that by modulating the size of the drag area (or porosity) you can significantly reduce the peak loads. Figures 39, 40, 41, and 42 provide data on Normal 'g', drogue drag, seat pitch, and seat/man velocity comparison for the MK-GRU7 type seat with a Martin-Baker duplex drogue system (22 inch controller drogue - 5 foot stabilizer drogue) for conditions of 600 knots at sea level and 1365 knots at 45 K feet, and the MK-GRU7 type seat with a two-stage drogue (2.5 foot initial drag increased to 5 foot drag 1.5 seconds later) for condition of 600 knots sea level. The data shows that the two-stage drogue acts in the following way:

- Reduces the peak Normal 'g' from 23 down to 9.5
- Reduces the drogue drag force from over 9000 pounds to 3000 on the first stage and 3500 pounds on the second stage
- Results in a 0.1 second increase in time to attain the same aft seat pitch angle of approximately 117 degrees, and reflects one in lieu of three oscillations prior to system stabilization
- Produces a flatter seat/man velocity decay, which means that if the main parachute is deployed at the same elapsed time, the seat/man velocity will be 450 feet/second instead of the 300 feet/second for the basic system. An additional 0.9 seconds is required for the two stage drogue system to slow the seat/man combination down to 300 feet/second. This time loss of course is unacceptable and must be traded off with higher speed parachute deployment which is treated in the next area, "Main Parachutes".

Main Parachutes

Main parachute opening shocks generally depend on the speed and air density at which the parachute is deployed. The success of the escape system is measured in terms of how quickly, within human tolerance and under adverse conditions, you can recover the crewman under a fully inflated parachute. Put these facts together and you are left with the basic problem of decelerating the entire system as fast as you can at an optimum controlled trajectory. You are also left with the decision: "If we sweeten the initial ejection phase by reducing the peak loads, can we afford to lose the time it takes to decelerate to a velocity that the main parachute can be deployed at?". It not, you must then trade time for energy and subject the crewman to higher but tolerable, and non-injurious main parachute deceleration forces by deploying the main parachute earlier at a higher velocity. There are several methods of doing this as discussed below:

- Stencel Aero Engineering's Ballistic Parachute Spreader is a device that ballistically propels small weights, that are attached to the skirt of the parachute, in a radial direction. At low velocity conditions, the parachute is spread out to gulp air for rapid inflation. At high velocities the mass of the weights is supposed to prevent rapid parachute opening
- A very standard technique of reefing the parachute can be employed to prevent explosive opening and to control the force/time deceleration
- High speed opening parachutes can be employed. Martin-Baker has introduced an aero-conical design into his MK-10 series seat systems.

2.5 REVIEW OF MK-GRU7 TYPE SYSTEM - EQUIPMENT AND PARACHUTE DAMAGE

Table 9 is a summary of personnel garments, survival equipment, drogue chute, and main parachute damage resulting from fourteen ejection seat tests conducted during six selected high speed sled tests. Test velocities varied from 435 to 600 KEAS. The A-6A and F-14 sleds were furnished with Martin-Baker MK-GRU7 and MK-GRU7A, zero-zero, rocket ejection seats respectively. The EA-6B sled incorporated the early Martin-Baker MK-GRUEA5, 100 knots on the deck, catapult ejection seats.

Due to the small sampling of ejection tests, the use of three different seat/cockpit configurations, the use of anthropomorphic dummies, and the fact that the majority of the ejections were through the overhead canopy make it unrealistic to come up with a statistical analysis of the damage; however, the following generalizations can be made regarding these dummy ejection tests:

- Through-the-canopy ejection is an overall saving of escape sequence time that results in more potential damage to the dummy and its equipment
- Ejection at velocities of 435 KEAS and above results in tears and fraying of the garments, broken helmet visors, opening of survival equipment, and in one case loss of a boot
- There is moderate to severe damage to the drogue and main parachute systems which will not contribute to potential crewman injury
- None of the damage or loss of equipment appears to have contributed to any loss of ejection system performance; however, when reviewing the data presented in reference 6, "AGARD Conference Proceedings No. 134 on

Escape Problems and Maneuvers in Combat Aircraft", and reference 7, "AGARD Conference Proceedings No. 170 on Biodynamic Response to Windblast", these effects could contribute to sufficient crewman injury to prevent post-ejection survival from all hostile (water, land, trees, enemy territory, etc.) environments.

2.6 REVIEW OF MK-GRU7 TYPE SYSTEM PARACHUTE CHARACTERISTICS

The characteristics of a parachute are very dependent on its design, material, and method of deployment. In an ejection seat escape system you must consider the total variation of recovered weight. The parachute system must recover the range of varied crewman percentile weight within human tolerance during the deceleration and landing impact phases. In addition, the system must be capable of minimum deployment and inflation time throughout the escape system's range of altitude and velocity, and be capable of being deployed in a manner that will not snag or entangle with the crewman or other portions of the escape system. It is desirable that the recovery parachute permit guidance by the crewman to an optimum landing site and in a direction that is best suited to the wind conditions.

The MK-GRU7 Type System Parachute is a standard 28 foot flat canopy that incorporates Martin-Baker's pull-down-vent lines. Controlled deployment and inflation of this parachute is carried out in the following manner:

- The duplex drogue system (Figure 43), anchored at the top of the seat, is deployed at a determined time to stabilize and orient the seat/crewman in a feet first/head aft position for downwind deployment of the main parachute. At low speed, an antisquid line in the stabilizer drogue relieves the force on the canopy/shroud line configuration to permit rapid inflation of this drogue for fast stabilization of the seat. At high speed, the small controller drogue squids the stabilizer drogue to cut down the drag force and resulting deceleration on the crewman
- At a determined time, within a specific altitude range, the crewman, his survival kit, his parachute, his restraints, and the duplex drogue system are released from the seat. The drogue system is now allowed to transfer its stabilizing force from the seat to open the parachute pack and deploy the main parachute downwind for controlled aerodynamic inflation
- Main parachute opening characteristics are controlled by airspeed and altitude. At low speeds, the pull-down-vent lines take the drogue drag force from the apex of the main parachute directly to the upper parachute riser links. This relieves the canopy/shroud line configuration from any initial drogue drag force and permits the canopy to rapidly inflate. At high speeds, the drogue drag force lengthens the pull-down-vent line geometry so that the drogue force goes directly into the parachute to retard its normal opening and reduce the initial opening shock on the crewman.

A review of the normal g for a 435 and 600 knot ejection at sea level, Figures 49 and 47 respectively, indicate that there are peak force pulses for drogue opening and main parachute opening. The drogue opening effects are discussed in the fourth paragraph of Section 2.4 and under Drogue Drag Modulation of the same section. Figures 49 and 47 show that the main parachute opening pulses are in the order of 10 to 13 g for the heavy crewman. Data from the 600 knot F-14 sled test, referred to in Table 9, shows that the heavy crewman sustained a maximum of 9.3 g, and the light crewman a maximum of 16.9 g, both over a .02 second time period.

2.7 SELECTION OF CREWMAN RETENTION SYSTEM

2.7.1 Best Approach

The best approach is considered to be the one that positively positions and holds the entire crewman's body to the ejection seat in a manner that will afford crewman protection against all environmental stresses and yet will not require the crewman to perform any unusual additional preflight or postflight operations.

The following sections, "Criteria", "Description", and "Design Concept/Substantiation" represent the selected approach developed under this program.

Approaches for the development of the restraint system were evaluated and selected for consideration through the development of the Evaluation Matrix presented by Figure 62. The design criteria for the retention system was selected based on the devices presented by Figure 63.

2.7.1.1 Criteria

The system will protect single or multiplace (command sequence) aircraft crewmen against aerodynamic and acceleration forces when ejecting in an open seat at airspeeds up to 600 knots and up to 45,000 ft. altitude. Ejection is initiated by a thigh level control. Protection is accomplished by retraction and retention of the crewman's arms and legs and support of his head. The systems concept is developed to be compatible as a system or technique for incorporation into new or retrofit Navy ejection seat systems. The system is integrated so that the crewman is unaware that he is provided with a head support/limb retention system. The concept does not require the crewman to perform any additional hook-ups beyond the present lap belt, shoulder harness, and leg garter arrangements on U.S. Navy Martin-Baker seats. The system permits use of the Navy integrated torso suit. The premise is that the applicable seat should incorporate the following systems or features:

- Headrest concavity to center the crewman's helmet and prevent it from sliding off the side of headrest
- Seat sides for preventing splaying of the legs, when properly restrained, from windblast
- A powered inertia reel to retract and restrain the crewman's upper torso to the seat structure
- A lap belt that is power tightened or properly adjusted to hold the crewman's hips to the seat
- A seat propulsion, stabilization, and recovery system that will prevent rapid rotation, deceleration, or yawing of the seat/man system beyond human tolerance
- An input signal for the initiation of the limb retention system's power retraction device and severance modes
- Protection from seat rocket blast when the crewman's legs are back against the front face of the seat
- A 0.250 second delay from ejection initiation to seat first movement.

2.7.1.2 Description

- Limb Restraint

Arm and leg restraint is accomplished by triggering a powered device on the seat that picks up snap-out retention lines integral to the crewman's garment. Retraction of these lines (one per arm and leg combination) pull and hold the wrists to the inside of the knees, the knees down so that the upper legs are held firmly to the seat cushion, and the lower legs back to be held firmly to the front surface of the seat. A spreader band, stowed in the region of the abdomen, pulls free to lodge between the wrists and knees to hold the knees and wrists together. This configuration keeps the elbows in and holds the skeletel structure of the crewman firmly so that it will not flail. During an ejection cycle the restraint lines are programed to be severed by a device on the seat to release the limb restraint system. For emergency exiting of the cockpit under non-ejection conditions the restraint lines will be severed at this point automatically by an input from whatever release system is provided by the seat.

See Figures 9 and 11 for basic concept of limb restraint system.

- Head Support

Head support is accomplished by inflating a device between the crewman's helmet and suit to make his head a rigid extension of his torso. Inflation is triggered automatically by movement of the limb restraint snap-out lines on the crewman's garment. The head support system is divorced from the seat system primarily to allow the head to follow the dynamic shift of the torso during the ejection cycle. Due to the sizes of the crewman population, it would be very difficult to select a common point of helmet attachment to the seat structure that would accommodate the dynamic shift as well as the variance of helmet locations. The device will be deflated, if required, at the appropriate time. No emergency release is required as the system is integral to the crewman's worn equipment and will not restrict crewman evacuation of the cockpit or seat.

The head support system eliminates the need for crewman preflight hookup, post-flight release, or automatic ejection sequence for release. Additionally, since the system is totally integral with the suit, it reduces the undesirable feature of having an exposed retraction system of straps, brackets, or cables that would have to be kept from snagging, interfering with the crewman's vision, or otherwise hampering his movements.

See Figures 9 and 11 for basic concept of the head support system.

- Crewman's Garment

The crewman's garment incorporates the limb retention/head support systems described above plus pockets for stowage of the crewman's carried survival equipment. The garment is worn as a top garment and comes in various sizes to accommodate the third through 98th percentile crewman. A front zippered ingress and egress is provided to allow the crewman quick donning or divestment and easy access for tightening torso cross strap.

The garment provides access to the four Navy torso harness fittings, anti "g" suit connection, and the exposure suit vent connection. This program phase does not consider integration of oxygen/communication line runs or repackaging of life preserver to clear restraint lines.

Other than connecting the two limb restraint lines, the four torso harness fittings, and the normal service connections, the garment system as concepted eliminates the need for crewman preflight hookup and post flight release of his retention and support systems. Also, since the systems are totally integral with the garment there is no possibility of snagging or hampering of the crewman's movements.

See Figure 9 and 11 for concept of crewman's garment described above. See also Figure 18, which reflects baseline concept for location of retraction lines and head support system.

- Limb Restraint Retraction Device

The limb restraint retraction device can be provided in several different design concepts depending on the type of ejection seat and cockpit configuration you are dealing with. A tilting seat pan or inflatable type of knee raising device will be required in those aircraft configurations where the legs do not have clearance to be positioned and restrained to the seat before seat movement. Listed below are several retraction device concepts.

(1) Three-to-one Mechanical Retraction. See Figure 16.

Employ a three-to-one mechanical retraction of the restraint lines through a one-way snubbing device on the seat. This scheme, like Martin-Baker's leg retention system, uses seat motion during the ejection sequence as the force to retract the restraint lines through the snubber. A suitable release or shear-out connection must be provided. This scheme has the advantage of being the simplest; but, it has the potential disadvantage of having to retract the arms upward, if they are in a low position, when under the influence of the ejection loads.

(2) Power Retraction Reel. See Figure 9.

Employ a power retraction reel to wind up the restraint lines independent of seat motion. The reel can be a high speed (many revolutions) small diameter drum device, or a slow speed (two revolution) large diameter drum device, depending on the available space.

(3) Power Retraction Gobbler.

Employ a power retraction gobbler device to pull-in the lines and either stow them in a contained area or let them fall free.

2.7.1.3 <u>Design Concept/Substantiation</u>

The design of the crewman restraint system is presented by Figures 9 and 11 to permit an understanding and visualization of the proposed concept in sufficient detail for prototyping.

The selected design concept is substantiated by the following figures, tables, etc. without the addition of a load safety factor.

- Table 8

This figure defines the maximum applicable crewman point loading that must be designed for to prevent the crewman from flailing or being dislodged from the seat.

- Tables 6 and 7

These tables define the maximum pressure and shear loads on the applicable crewman's surfaces. The maximum pressures are shown to be within the human tolerance limits specified in Section 2.2 of this report.

- Figure 62 lists the protective devices that were evaluated and selected for consideration.

- Figure 63 shows what protection requirement each selected device satisfies.

2.7.2 Alternate Approaches

The following alternate crewman restraint concept approaches are compatible to the present crewman's garments and survival equipment that he wears upon entering the cockpit.

Figure 64 depicts the installation of a Belt Grabber Restraint concept. The belt is stowed on an inverted horseshoe frame that is pivoted from the rear cockpit bulkhead. Upon ejection initiation, the crewman's torso is pulled back and restrained to the seat back by the shoulder harness-powered inertia reel, his thighs are elevated to insure thigh/seat surface contact, and then the belt frame is articulated forward to sweep the upper arms inward and place the belt in a position so that when the two belt retraction reels are fired, the belt will snap down to entrap and hold the arms and thighs to the seat. The belt frame is articulated back to clear the ejection envelope. Lower leg retention is accomplished by a Martin-Baker type leg garter system. Belt release occurs at seat/man separation.

Figure 65 depicts the installation of a Pillow/Belt Grabber Restraint concept. The belt and pillows are stowed on an inverted horseshoe shell frame that is pivoted from the seat sides. Upon ejection initiation, the crewman's torso is pulled back and restrained to the seat back by the shoulder harness powered inertia reel, his thighs are elevated to insure thigh/seat surface contact, and then the pillow/belt shell frame is articulated forward to sweep the upper arms inward and place the pillow/belt in a position so that when the two belt retraction reels are fired, the belt will snap down and initiate pillow inflation. An external pillow will inflate as a rigid continuation of the shell frame to form a contoured protective windblast shield. An inner pillow will inflate to softly fill the area between the inner surface of the rigid pillow and the crewman's head, torso, arms, and thighs in a manner which will not create pressure points on the crewman, due to the irregular nature of the survival equipment he is wearing, and to accommodate the percentile range. The belt acts as the force to hold the pillows to the seat for entrapment of the crewman's arms and thighs, and support of his head. Lower leg retention is accomplished by a Martin-Baker type leg garter system. Release of the Pillow/Belt configuration occurs at seat/man separation.

Figure 66 depicts the installation and operational concept of a Sweep and Grip restraint system. Each of the six gripper assemblies are made up of two elements that are connected by a flexible web, and mounted to a common cone pivotable base. The web provides a large surface contact area to distribute the gripping force on the crewman. The cone pivotable base permits the gripper assembly to be articulated from the stowed position into a sweeping arc (out and then back in) to force the limbs inward. The elements are pressurized as required to curl and hold the limbs immobile. Upon ejection initiation the crewman's torso is pulled back and restrained to the seat back by the shoulder harness powered inertia reel, his thighs are elevated to insure thigh/seat surface contact, and then the gripper assemblies are articulated to sweep the limbs inward. The upper and lower arm grippers now curl to hold the arms and thighs immobile. The leg gripper curl action is initiated during the ejection phase of the guided seat travel when the lower legs have pendulumed back against the front of the seat due to the ejection forces. Gripper release occurs at seat/man separation.

2.8 SYSTEMS FOR IMPROVEMENT OF CREWMAN PROTECTION

Section 2.7 deals with the ground rules and selection of the Crewman's Retention System. Section 2.8 deals with other than restraint methods and techniques for protecting the crewman against the violent environment of a 600 KEAS ejection.

Figure 62 lists the protective devices that were evaluated and selected for consideration. Figure 63 includes each of these selected devices and shows what protection requirement it satisfies. Below, each one of the Protective Devices are discussed to show their contribution to Crewman's Protection.

Inflatable Support

The inflatable device shown by Figure 5 raises the crewman's thighs, not only to provide cockpit floor clearance, but to reduce the frontal drag area of the seat/man combination which will reflect a reduction of deceleration forces. This device also permits the stabilization/deceleration system to pick up more drag authority provided the system combination is within human tolerance. See Inflatables, Section 2.3.

Full Face Helmet

The full face helmet concept, depicted by Figure 11, provides the crewman with windblast protection of his face and eliminates the potential loss of his oxygen mask and/or helmet.

The helmet should be lighter, stronger, absorb impact better, have better C.G.

location, incorporate ventilation, incorporate communications and oxygen servicing input without visual or crewman mobility infringements, protect against biological and chemical warfare, be aerodynamically stable, be more comfortable, and be quickly donned/doffed. The helmet configuration should consider compatibility to the High Acceleration Cockpit needs and restrictions. The face glass should consider the aspects of being selectively darkened, color controlled for maximum recognition under high g forces, with the option of selectable optical magnification and projection of flight and data displays.

Foetal Positioning

Foetal positioning, beyond what is depicted by Figure 5, will lessen the frontal drag area to reduce the deceleration forces, and place the legs in a position to partially protect the abdominal area from direct windblast. See Foetal Position, Section 2.3.

45 Degree Ejection Angle

Ejecting in a 45 degree aftward angle, as depicted by Figure 17, potentially does two things of value. First there is better windblast protection of the crewman's torso area, and secondly the drag area is so reduced that >600 KEAS Ejection capabilities can be considered without exceeding human tolerance. See Ejection Direction, Section 2.4.

Windscreen

The windscreen concept depicted by Figure 15 will potentially reduce the windblast forces on the crewman as he is riding up the ejection rails in a constant $\bar{q}$ force field, and during the initial phase of separating from the aircraft. See Wind Deflectors/Canopy Shielding, Section 2.4.

Modulated Drogue

A modulated drogue chute system can provide two assets to improve crewman protection. First, a drogue chute will provide for excellent seat/man stabilization within human tolerance provided that the seat/man combination is stabilized at the proper attitude during its deployment phase. Secondly, the ability to modulate (change drag characteristics) will allow the crewman to be decelerated maximumly within the requirements of the escape system. See Drogue Drag Modulation, Section 2.4.

Afterbody

An aerodynamic afterbody concept, depicted by Figure 10, can not only provide for seat orientation and stabilization throughout the entire seat/man trajectory, but provide a degree of streamlining to reduce the system drag and open the door to 2000 P.S.F. open ejection seat escape systems. See "Aerodynamic Devices" and Streamlining, Section 2.4.

Thrust Vector Control

Thrust Vector Control, discussed under "Thrust Devices" of Section 2.4, is a seat/man stabilization device which only performs its function during the very short thrusting period after aircraft separation, and will require an additional stabilizing system when decelerating from the higher speeds.

D.A.R.T.

D.A.R.T., discussed under "Mechanical Devices," Section 2.4, performs the task of stabilizing the seat/man configuration during the initial phase of exiting the aircraft, and will require an additional stabilizing system to cover the time period up to main parachute deployment.

Ballistic Spreader

The Ballistic Parachute Spreader, discussed under Main Parachutes, Section 2.4, is a device to sweeten the opening shock on a crewman without deteriorating the zero-zero ejection capabilities.

Reefing

A very standard technique of reefing the parachute can be employed to prevent explosive opening and to control the force/time deceleration.

Aero-Conical

The Aero-Conical parachute has been introduced by Martin-Baker into his Mk-10 series seat systems to reduce opening shocks on the crewman without deteriorating the zero-zero ejection capabilities.

Section 3

CONCLUSIONS

The considerable theoretical, analytical, literature review, computer data processing, and conceptual design effort described in this report has resulted in the determination of the most severe environment constraints imposed upon a crewman, the development of a crewman retention system concept, and the selection of various protective devices for his protection against high speed escape through the 600 knot speed range in open escape seats.

From careful review of the literature presented by reference (8), the Naval Safety Center calendar year publication "Emergency Airborne Escape Summary"; reference (9), Rice, E.V., and E.H. Ninow "Man-Machine Interface: A Study of Injuries Incurred During Ejection from U.S. Navy Aircraft"; reference (6), Advisory Group for Aerospace Research and Development "AGARD Conference Proceedings No. 134 on Escape Problems and Maneuvers in Combat Aircraft", specifically papers (A1) and (A4); and reference (7) "AGARD Conference Proceedings No. 170 on Biodynamic Response to Windblast", it can be firmly stated that a real-world problem exists in that crewman are being injured and survival equipment is being damaged during high speed ejections. Positive action must be taken to develop, qualify, and incorporate protective devices for the crewman population.

From careful examination of the work conducted during this program the following is concluded.

(a) Regarding Base Line Conditions and Configurations (Section 2.1)

The existing Martin-Baker MK-GRU7 type ejection seat was used as a datum ejection seat system, and eight different crewman positions and/or percentiles were used to examine the minimum number of worst configurations for analysis. Grumman computer programs were exercised to match the actual ejection test data. The data generated by the many figures included in this report show the validity of the output.

(b) Regarding Design Constraints (Section 2.2)

Table 8 presents the maximum restraint forces required to restrain the crewman's head and extremities from flailing due to windblast and acceleration forces developed during a 600 KEAS ejection with the datum seat. These forces can be easily overcome by the crewman restraint system concept presented by Figures 9 and 11 of this report. The additional protective devices listed in Figure 63 will reduce the severity of the restraint requirements in accordance with the specific designs purpose.

(c) Regarding Windblast (Section 2.2)

Regardless of what type of existing open ejection seat system is being used, the severity of windblast forces during the initial ride up the guide tracks and immediately following aircraft separation are the greatest forces encountered which will contribute to direct pressure injury to an unprotected face, survival equipment damage, and flail injury to the head and extremities.

Figure 20 lists the maximum pounds per square foot on each segment of the crewman's body, and Table 6 lists the maximum force on each body member due to windblast effects at 600 knots sea level.

Figures 51 and 58, right arm out horizontally to the side and right leg out 90 degrees to the side respectively, indicate very vividly by the data on these flail conditions the enormous instability of the seat/man configuration during a 600 KEAS ejection with the potential failure of the escape system.

Reference (7), "AGARD Conference Proceedings No. 170 on Biodynamic Response to Windblast", documents the loss of a crewman helmet, attributed to the areodynamic lifting moment of some 460 pounds at 600 knots, which will cause severe head and neck injuries. This reference also points out the significant, and even fatal damage that can occur to an unprotected face and an unsupported or restrained head or extremities.

Table 9, which lists damage to the crewman's garments and survival equipment, vividly reflects the fact that even though the overhead canopy is jettisonned prior to ejection, (as on the F-14 aircraft) there is damage to or loss of equipment. It appears that windblast forces can severely flutter loose materials to initiate a failure. This indicates that multiple add-on systems like life preservers, survival vests, knee boards, personnel armor, oxygen/communication lines, chest mounted oxygen regulators, oxygen masks, restraint harnesses, anti-exposure suits, flight suits, helmets, etc. should be integrated to the greatest practicable degree. Figure 11 depicts a conceptual approach.

(d) Regarding Acceleration Forces (Section 2.2)

Acceleration forces must be looked at in two ways. If the force is linear, as during the initial guided travel and a stabilized deceleration, the force/time curve can be easily accommodated within human tolerance for a 600 KEAS ejection. If the acceleration forces include rotational forces, due to the seat/man configuration seeking its trim position, or to extremity flailing, or to stabilization system deployment seat trimming, or to excessive steering requirements imposed on a Thrust Vector Control System, then these forces can become large enough to injure the crewman if he is not adequately protected. Figures 21, 22, 23, 29, and 30 are typical examples of the acceleration forces imposed upon the head, lower leg, upper leg, upper arm, and lower arm respectively. It should be noted that the maximum acceleration occurs during the period of drogue deployment for seat stabilization and deceleration.

(e) Regarding Thermal Conditions (Section 2.2)

There is no indication based on ejection history, tests, or theoretical analysis that crewmen will be subjected to thermal injury during a 1220 P.S.F. open seat ejection between sea level and 45K feet. Figures 13 and 14 plot long term temperature exposures which appear to be in the order of 300 degrees F at 45K feet for a sustained 600 KEAS velocity. This of course is unrealistic since the seat/man configuration immediately decelerates. Reference (5), Report No. AMRL-TR-76-2 "The Heat Pulse Associated with Escape from an Aircraft at Supersonic Speed", shows that thermal injury will not be a problem at an ejection $\bar{q}$ of 1220 P.S.F.

(f) Regarding Survival Equipment and Parachute Damage (Section 2.5)

The MK-GRU7 datum seat system reveals by the data in Table 9 that through-the-canopy ejections, and ejection velocities of 435 KEAS and above result in more potential damage to the survival equipment and parachutes. None of this damage or loss of equipment appears to have contributed to loss of ejection system performance; however, the data presented in references 6 and 7, AGARD Conference Proceedings No. 134 and 170 respectively, indicate that these effects could contribute to sufficient crewman injury to prevent post-ejection survival from all hostile environments.

(g) Regarding Human Tolerance to Acceleration Forces (Section 2.2)

Figures (1), (2), (3), and (4) of Appendix A, "Physiological Tolerance to Acceleration and Deceleration Forces", define an update of the transverse, lateral, positive vertical, and negative vertical g tolerance levels for crewmen. These tolerances will not be exceeded with a properly ejected, stabilized, decelerated, and parachute recovered crewman ejection system.

(h) Regarding Protection Methods and Techniques Investigated (Section 2.3 and 2.4)

Figure 62 is an Evaluation Matrix that lists and evaluates each appropriate Method and Technique for selection of consideration. Figure 63 takes the selected items and shows where they apply in regard to the restraint system as well as for the additional protective devices.

These additional protective devices for improvement of crewmen protection are discussed in Section 2.8. Listed below are their main contributions.

"Inflatable Support" for repositioning of the thighs, "Foetal Positioning", "45 Degree Ejection Angle", and "Afterbody" are all systems that contribute to initial reduction of drag deceleration.

A "Full Face Helmet", "Foetal Positioning", "45 Degree Ejection Angle", and "Windscreen" are all systems that contribute to reduction of windblast damage.

A "Thrust Vector Control" and a new conceptual approach for "D.A.R.T." are both systems to contribute to seat/man stabilization through the initial phase of exiting the aircraft. A "Modulated Drogue" and "Afterbody" are both systems for seat/man stabilization throughout the entire trajectory to main parachute deployment provided they are initially deployed to prevent erratic seat movement at aircraft separation.

A "Modulated Drogue", a new conceptual approach for "Ballistic Spreader", "Reefing", and "Aero-Conical" are all systems that contribute to reduction of parachute opening shocks on the crewman.

(i) Regarding Selection of Crewman Retention System (Section 2.7)

The best approach is considered to be the one that positively positions and holds the entire crewman's body to the ejection seat in a manner that will afford crewman protection against all environmental stresses and yet will not require the crewman to perform any unusual additional preflight or postflight operations.

Figure 9 depicts the concept of the retention system, and Figure 11 shows a concepted integrated mission/survival garment system.

Figure 63, "Matrix for Selection of Crewman Retention System and Protective Devices", substantiates the design concept selection.

Table 8 lists the maximum restraint forces required to hold the crewman's extremities to the seat during a 1220 P.S.F. ejection.

Section 4

RECOMMENDATIONS

Based on the work conducted and the conclusions reported, the following recommendations are made for providing the crewman with a retention system, and additional protective devices for his protection against high speed escape through the 600-knot speed range in open escape seats. Note that the recommendations that deal with the category of additional protective devices do not necessarily apply for all escape systems. Each recommendation must be analyzed for its ability, first to be compatible, and then to contribute to the improvement of the particular escape system in question.

a) Develop the "Integrated Mission/Survival Garment System" concept depicted by Figure 11, and discussed in Section 2.7. This garment will act as the foundation for part of the protective devices and will eliminate windblast damage to the crewman and his equipment. Special effort should be made to eliminate, redesign, and/or relocate all the survival equipment presently worn or supported by the crewman so as not to encumber him with heavy, bulky uncomfortable, and tiring equipment that presently contributes to the deterioration of his mission performance.

b) Develop the "Head, Arm, and Leg Retention System" concept depicted by Figure 9, and described in Section 2.7. This concept positively positions and restrains the crewman without additional crewman operations.

c) Develop the "Full Face Helmet", described in Section 2.8 primarily to eliminate windblast and aerodynamic lift forces.

d) Develop the "Inflatable Support", described in Section 2.8, primarily to provide foot/floor clearance, and reduce frontal drag.

e) Consider "Foetal Positioning", described in Section 2.3, for new high $\bar{q}$ escape systems.

f) Consider "45 Degree Ejection Angle", described in Section 2.4, for new high $\bar{q}$ and/or high acceleration cockpit escape system requirements.

g) Consider the "Windscreen" concept, described in Section 2.4, for new aircraft where the device can be cost effective for improving maintenance in that area of the aircraft.

h) Develop the "Modulated Drogue" concept, described in Section 2.4, for those present escape systems that are subjecting the crewman to unnecessarily high deceleration and opening shock forces.

i) Develop and evaluate by test the feasibility of the aerodynamic "Afterbody" concept, described in Section 2.4, for potential use on existing and new high $\bar{q}$ escape systems.

j). Continue the development of "Thrust Vector Control", described in Section 2.4, for application on new technology seats, such as NADC's Maximum Performance Escape System, the Air Force's Advanced Concept Escape System, etc.

k) Consider the incorporation of a new conceptual approach for "D.A.R.T.", described in Section 2.4, on those escape systems that show violent instability on aircraft separation.

l) Consider the incorporation of a new conceptual approach for the "Ballistic Parachute Spreader", described in Section 2.4, on those escape systems that require better low speed main parachute opening characteristics as well as high speed opening shock reduction.

m) Consider "Reefing" techniques, for reducing explosive parachute opening, for those escape systems that are subjecting the crewman to unnecessary deceleration and/or parachute opening forces.

n) Pursue the investigation of the "Aero-Conical", or other main parachute concepts that will reduce the opening and deceleration forces on the crewman.

o) Review existing and proposed escape systems for the addition of fixed or erectable structural support for the crewman's head and legs.

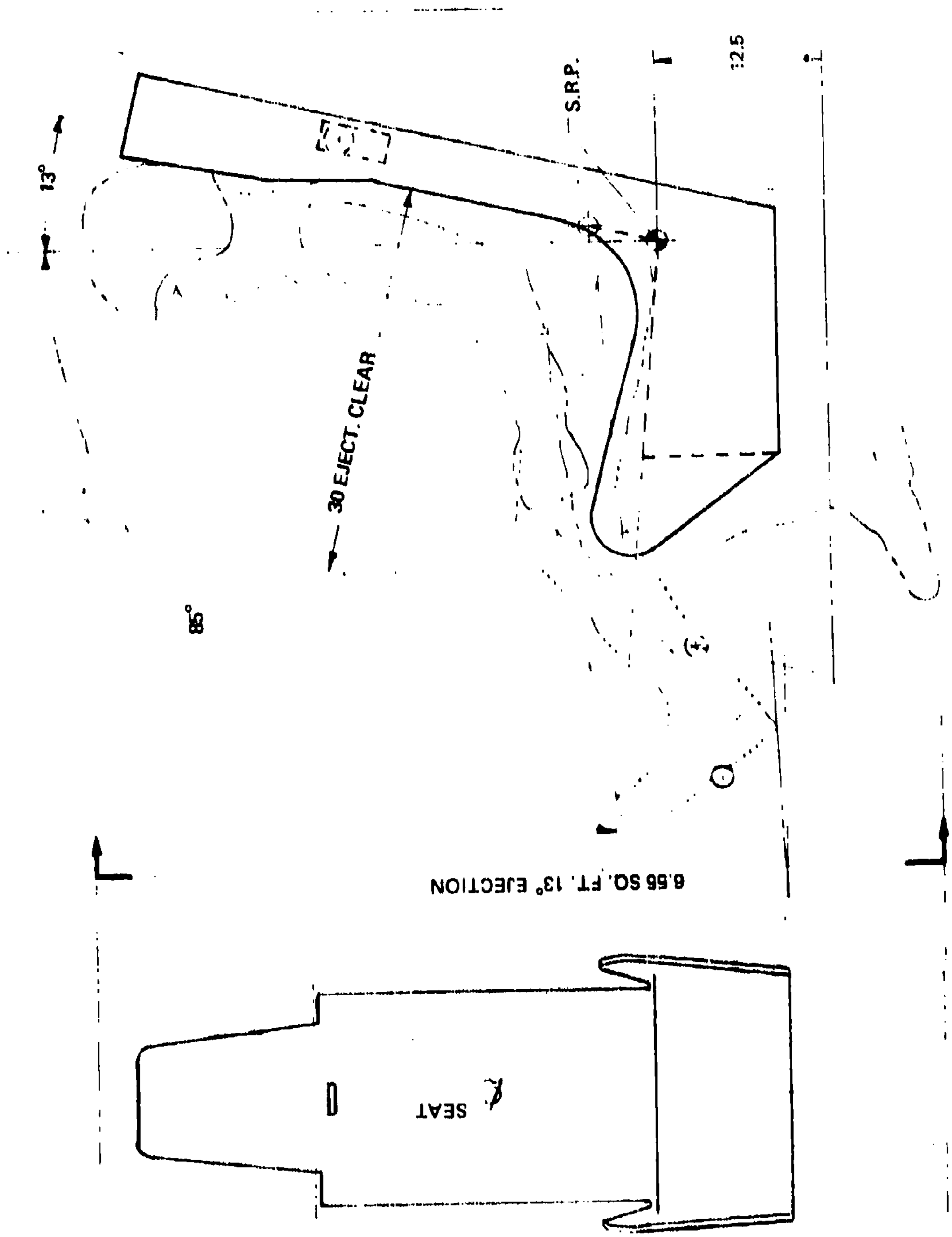


Figure 1 Typical Datum Seat

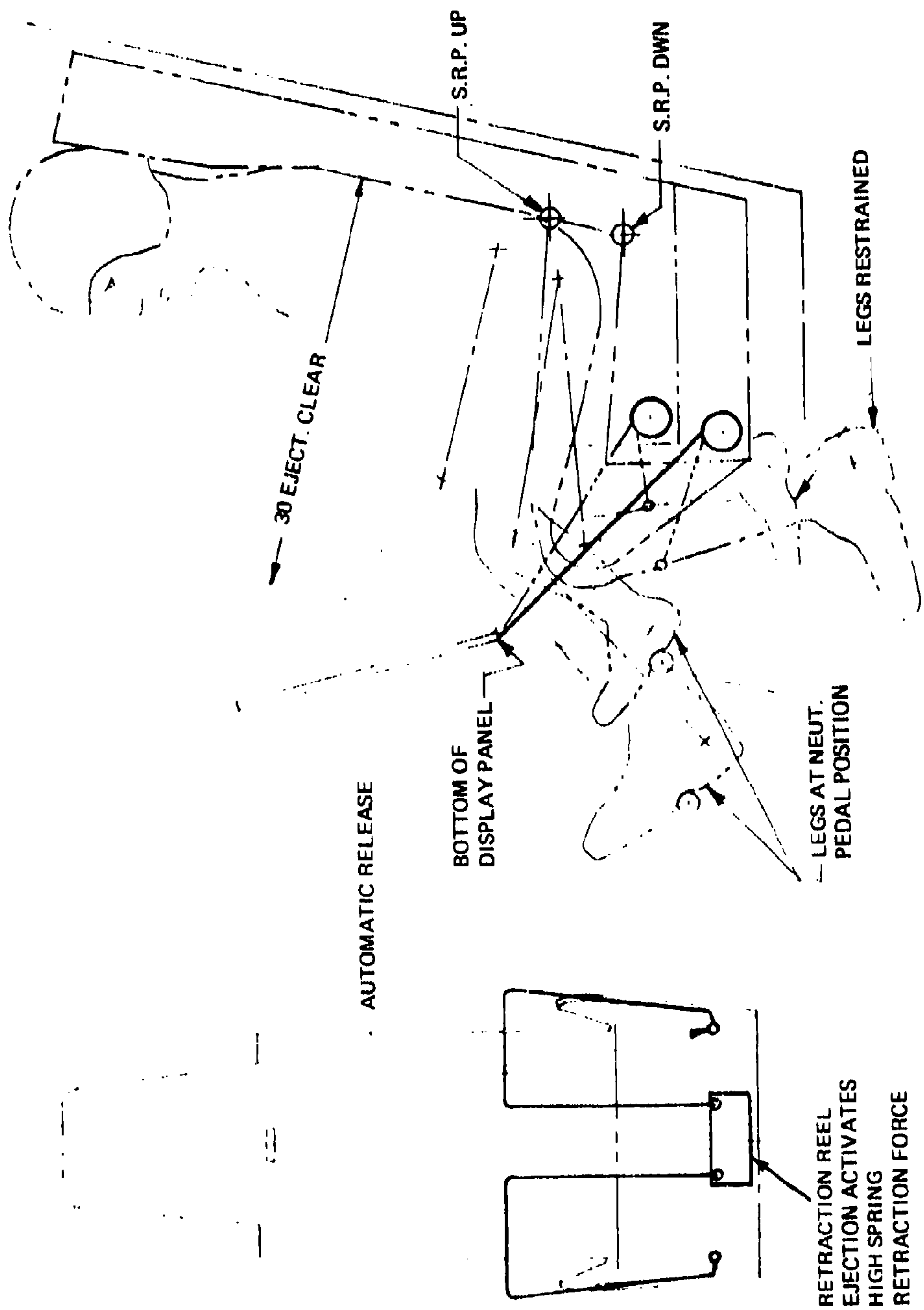


Figure 2 Datum Seat/Step-Into Lower Leg Restraint

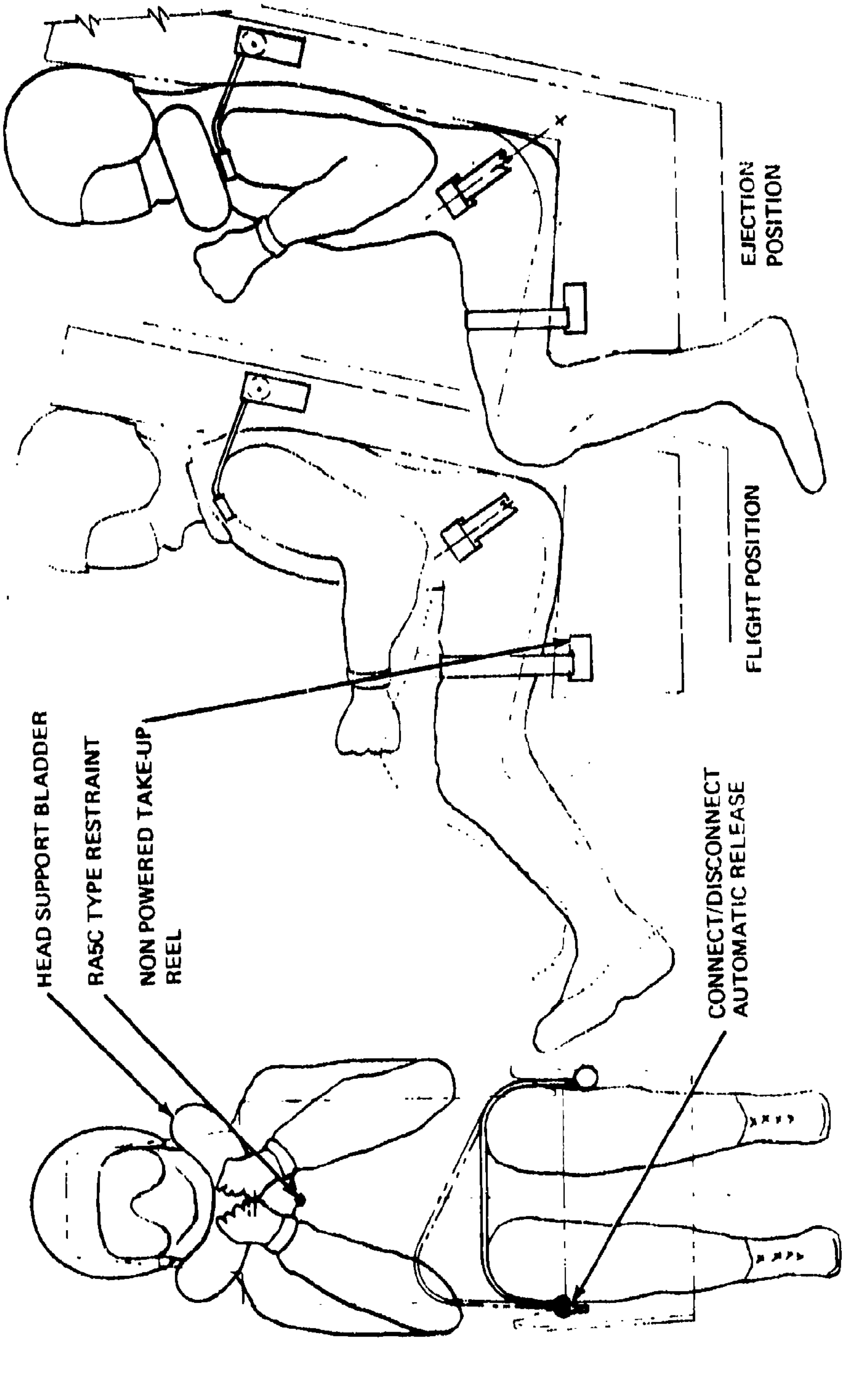


Figure 3 Datum Seat/RA5C Type Arm Restraint—Non Powered Thigh Restraint Take-Up Reel

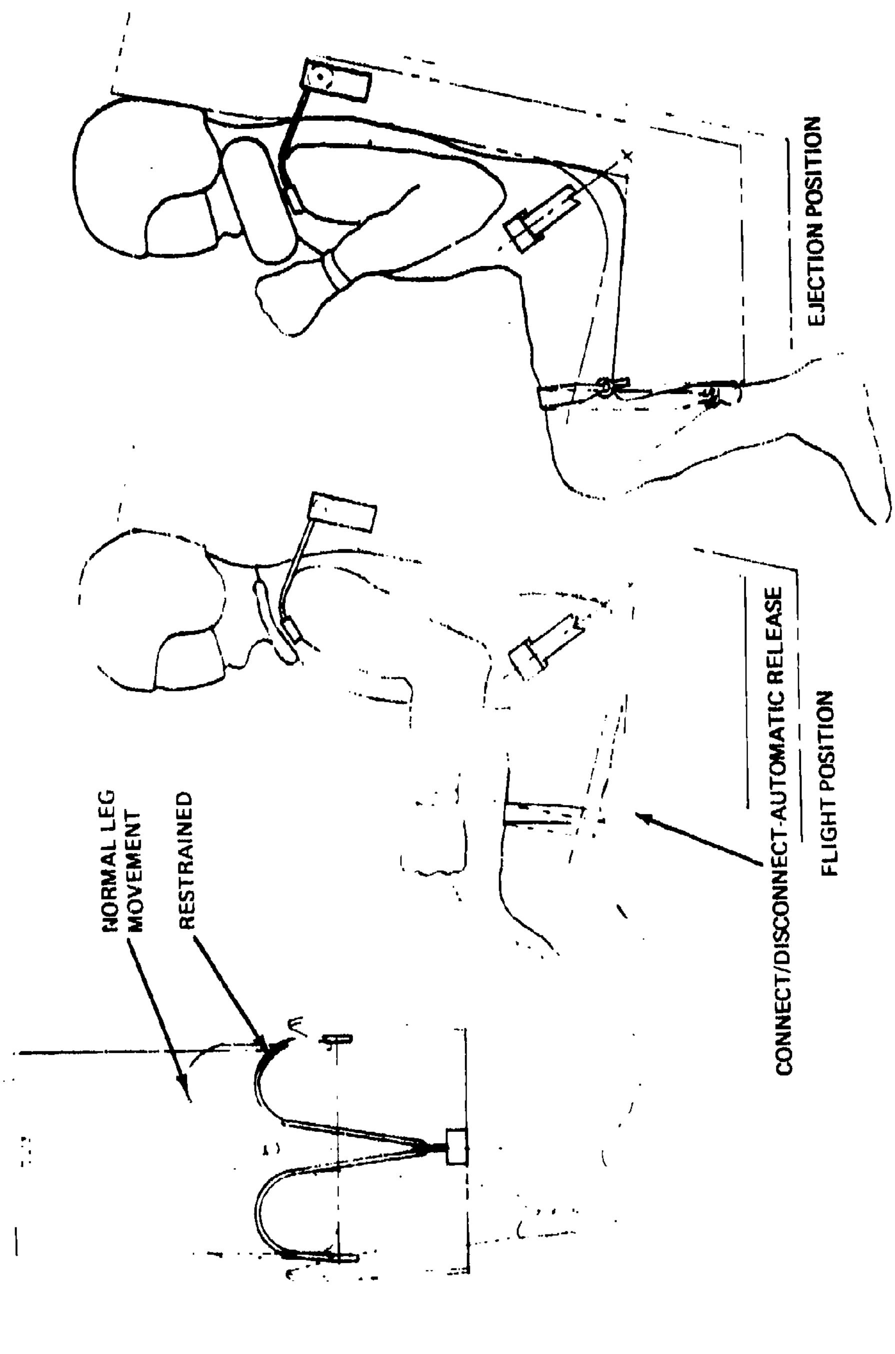


Figure 4 Datum Seat/RA5C Type Arm Restraint - Non Powered Thigh Restraint Take-Up Reel

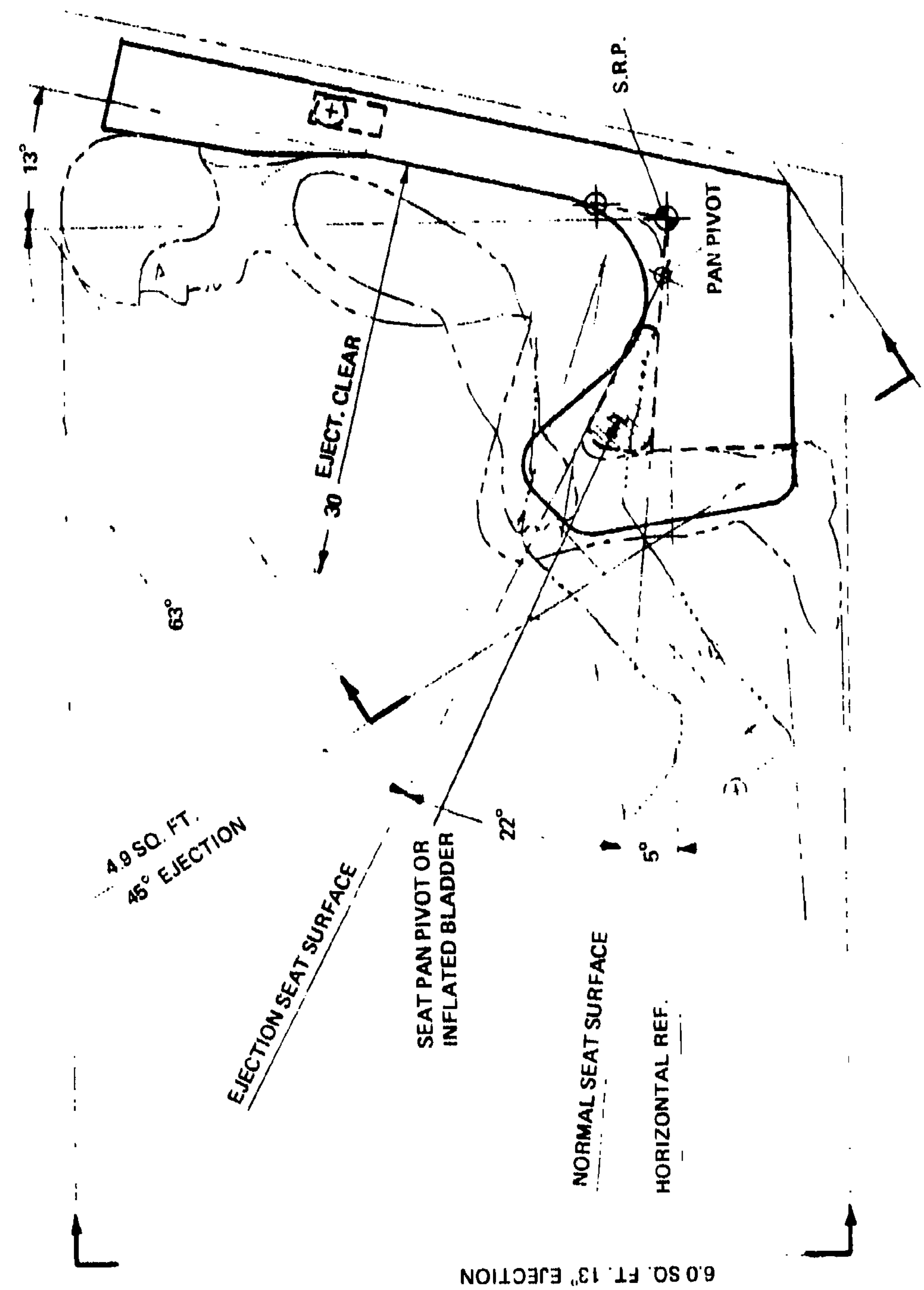


Figure 5 Datum Seat/Frontal Area Reduction & Foot Floor Clearance

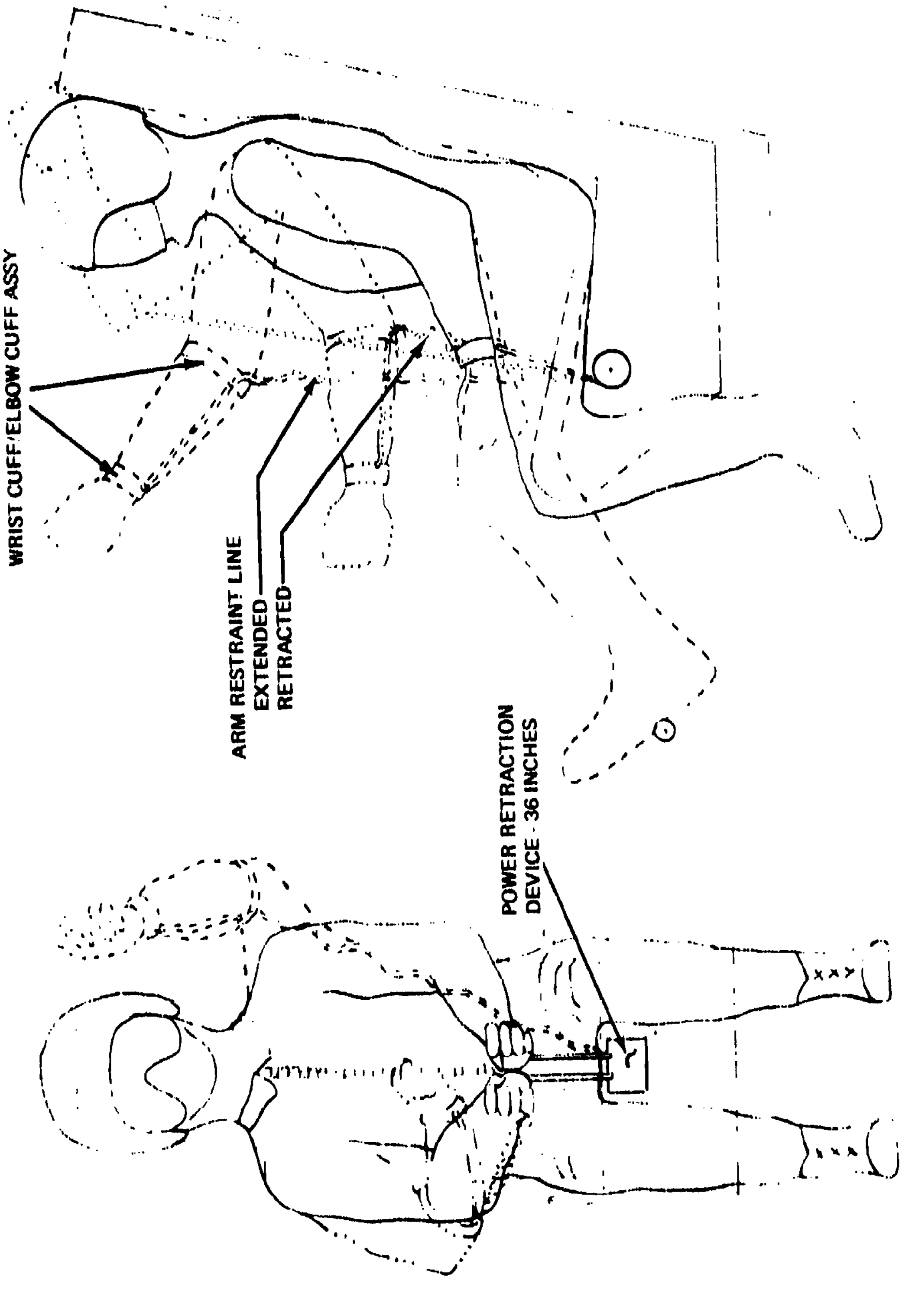


Figure 6 Datum Seat/Power Retraction - Wrist/Elbow Cuff Assy

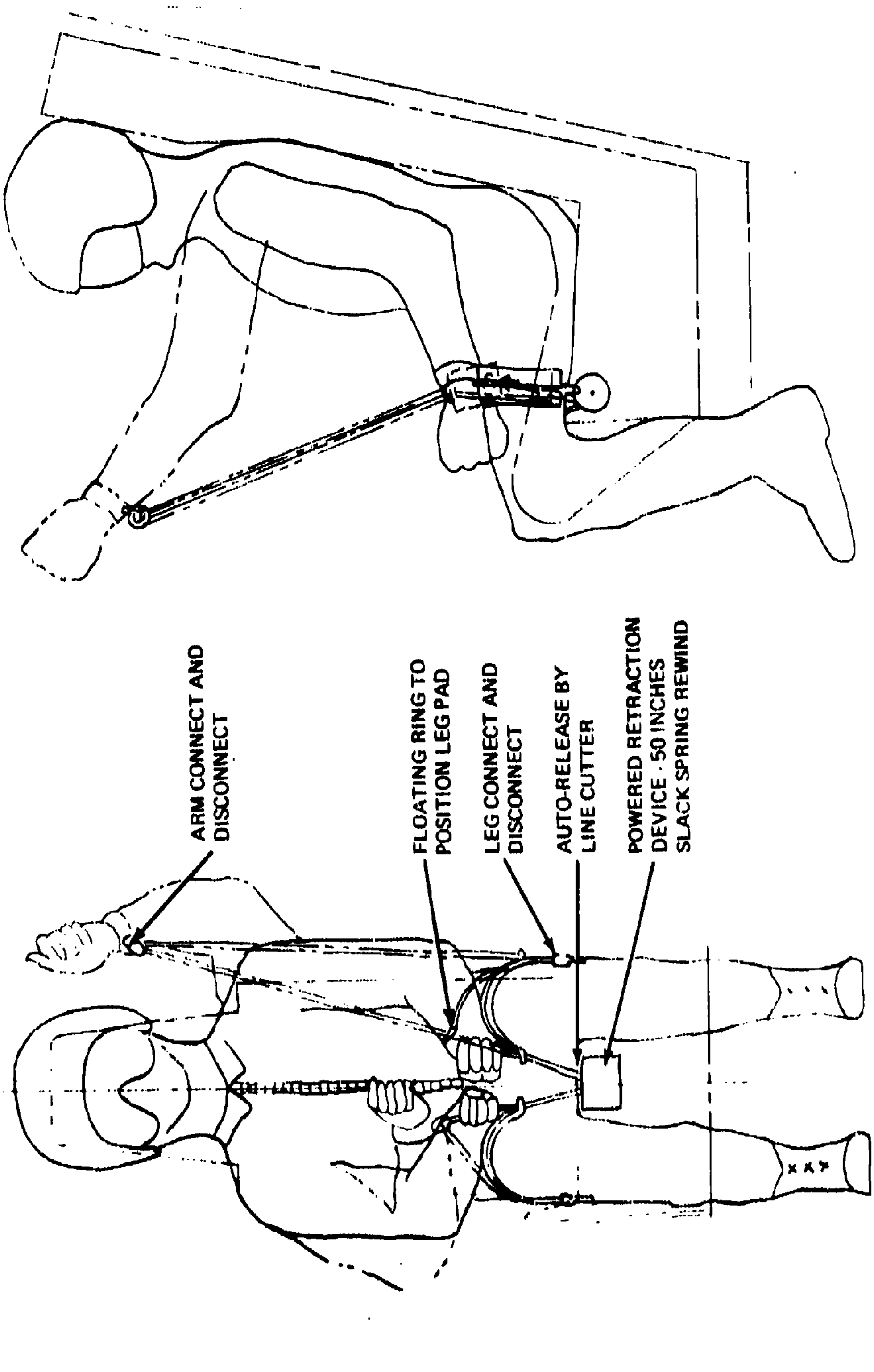


Figure 7 Datum Seat/Power Retraction - Arms and Thighs

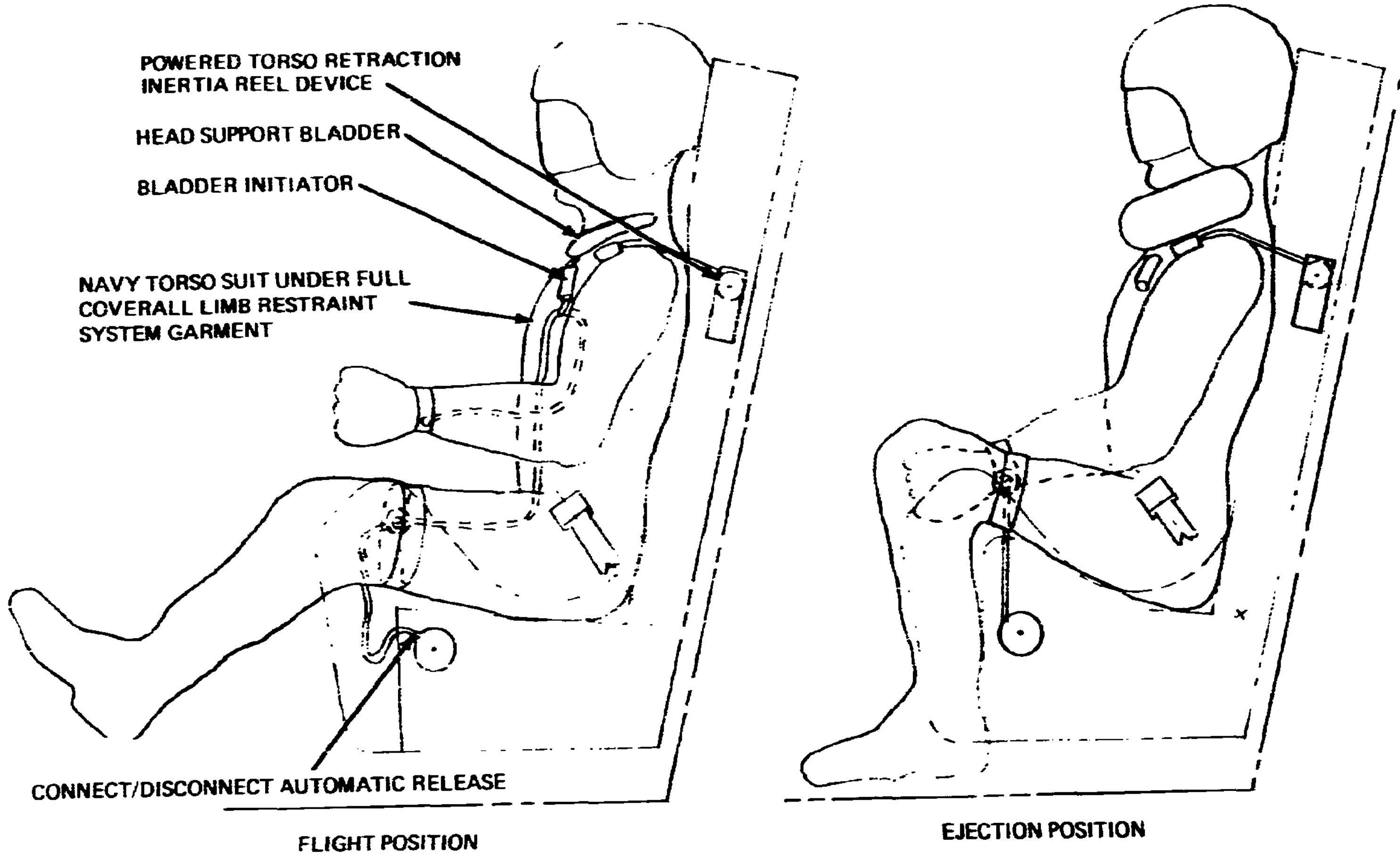


Figure 8 Datum Seat/Powered - Head, Torso, Arms, Upper Legs Restraint

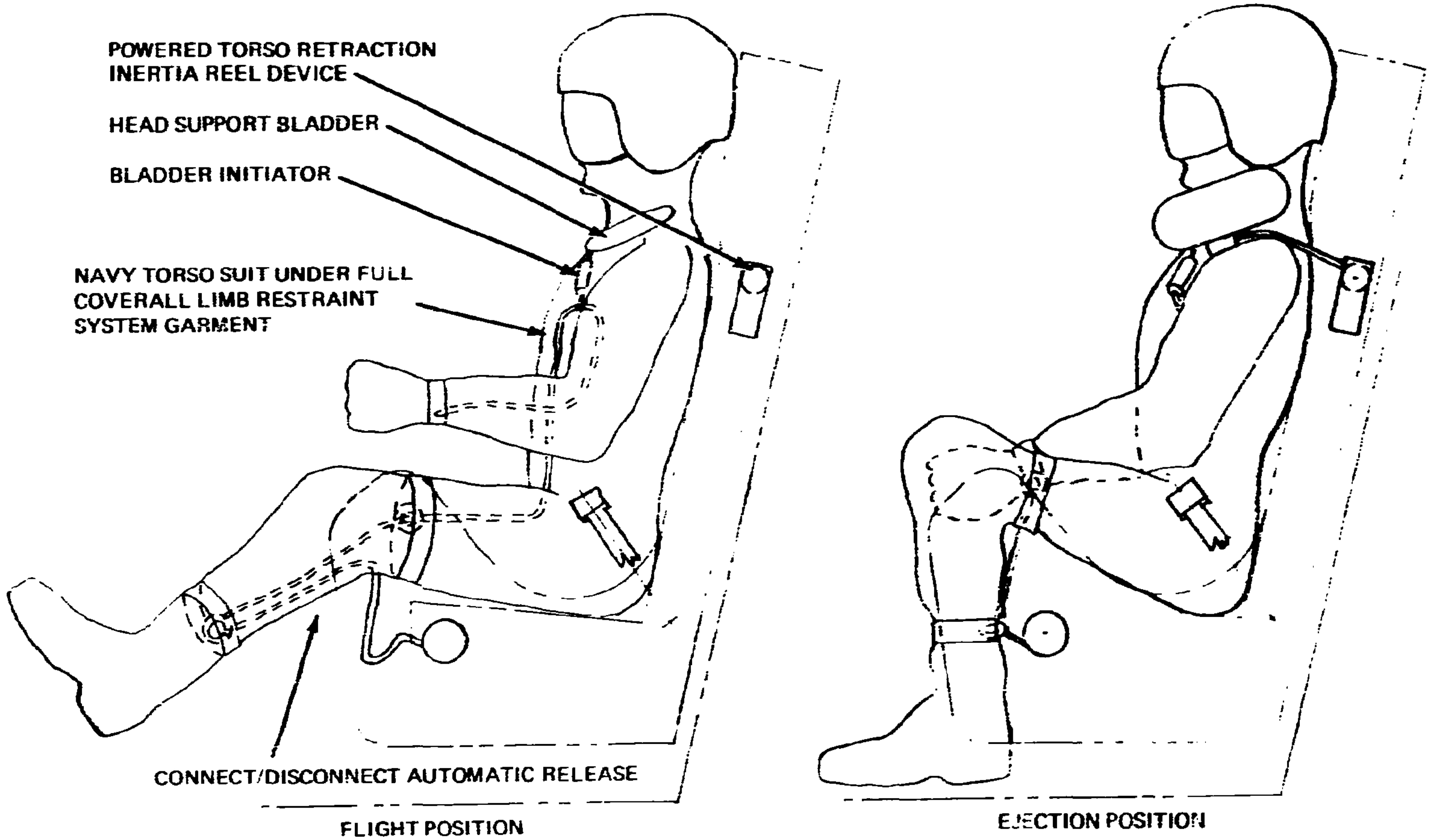


Figure 9 Datum Seat/Powered-Head, Torso, Arms, Upper & Lower Legs Restraint

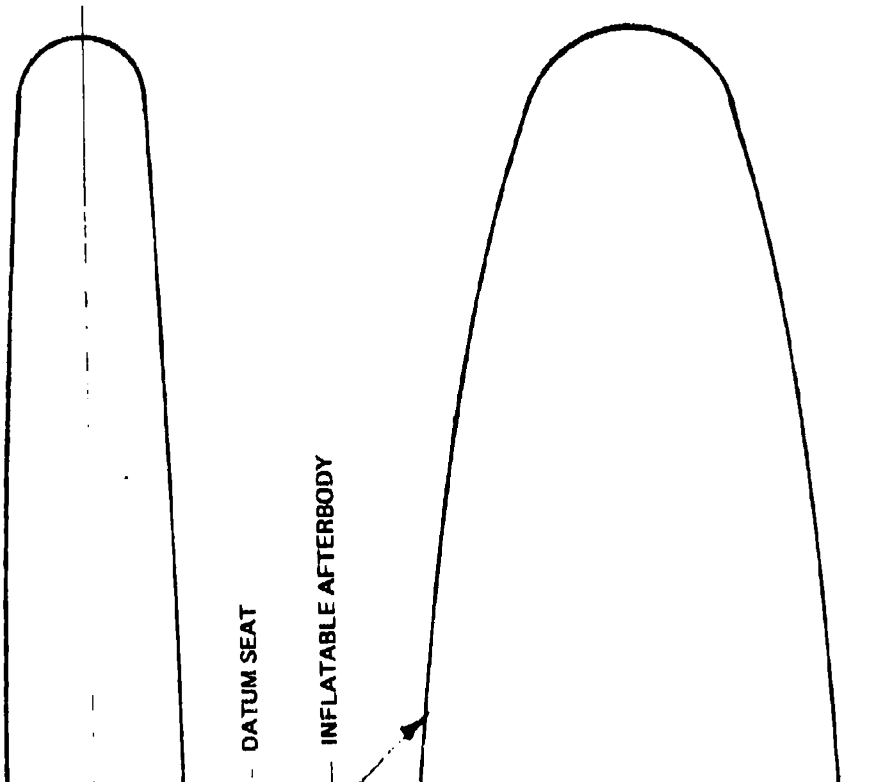


Figure 10 Inflatable Afterbody Concept/Ejection Seat Stabilization Without Drogue Chutes/Improved Streamlining/Reduced Deceleration Forces

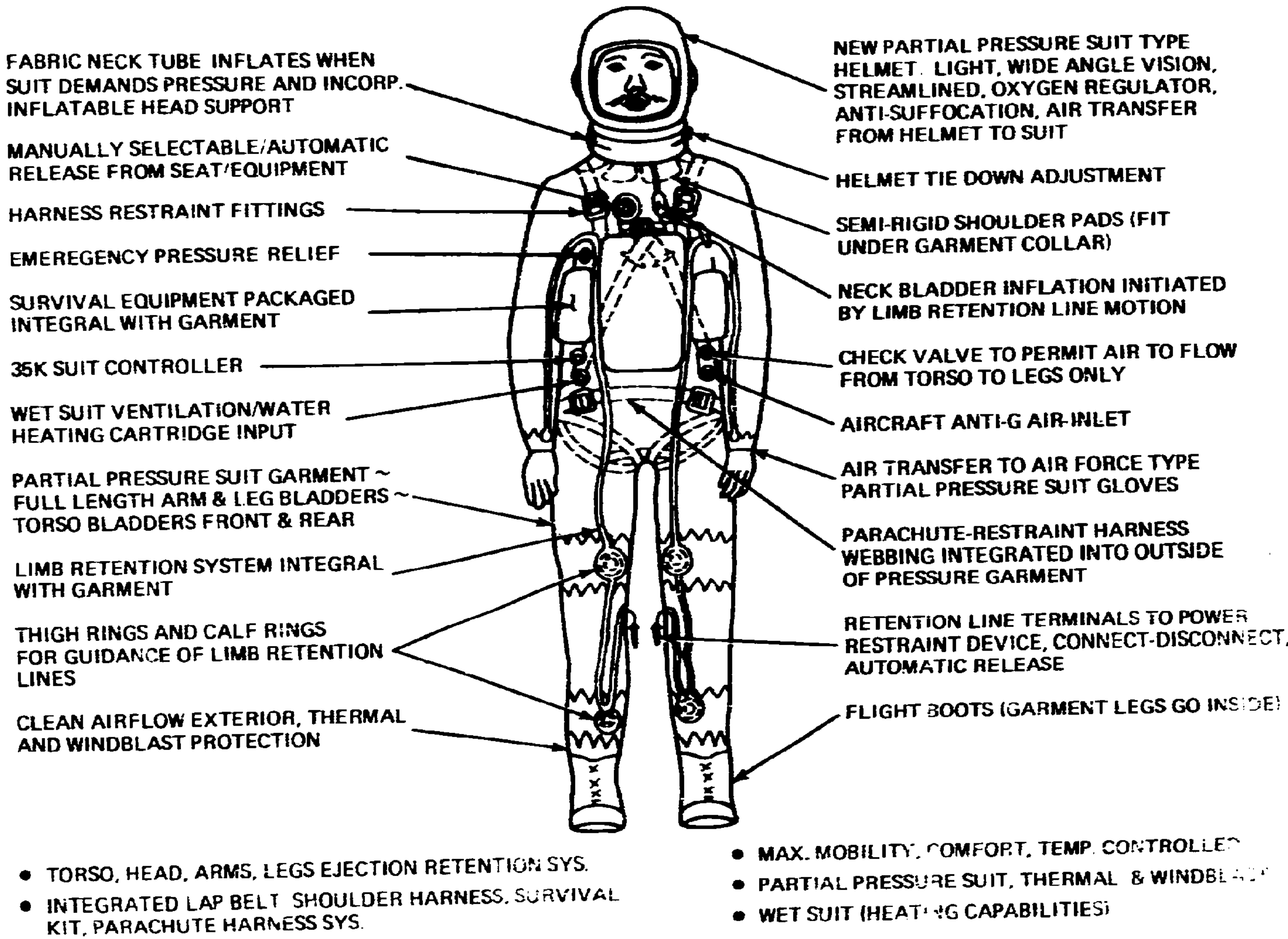


Figure 11 Integrated Mission/Survival Garment System

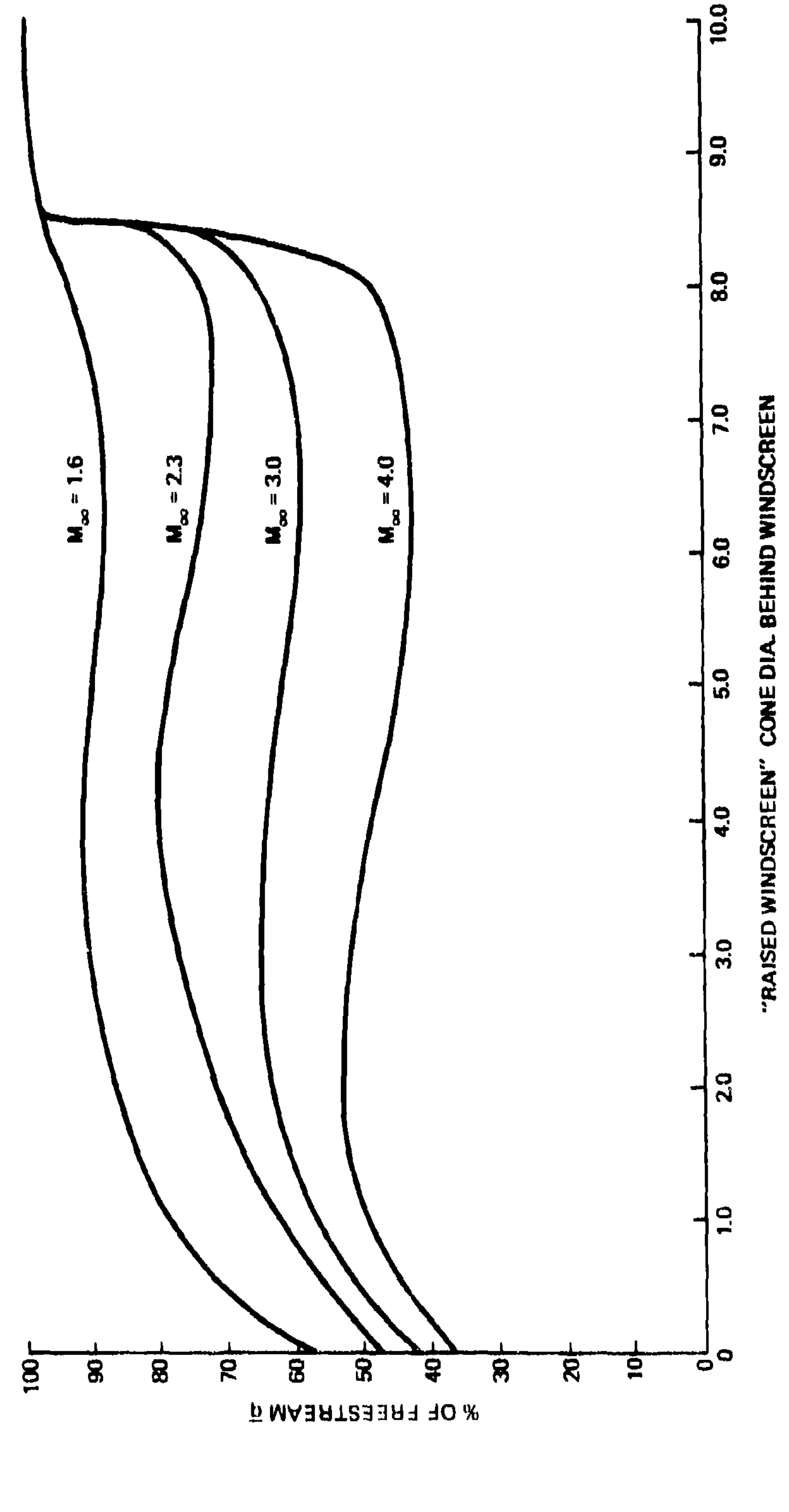


Figure 12 $\bar{q}$ Reduction Behind Raised Windscreen On C.P. of Man Off Ejection Rails

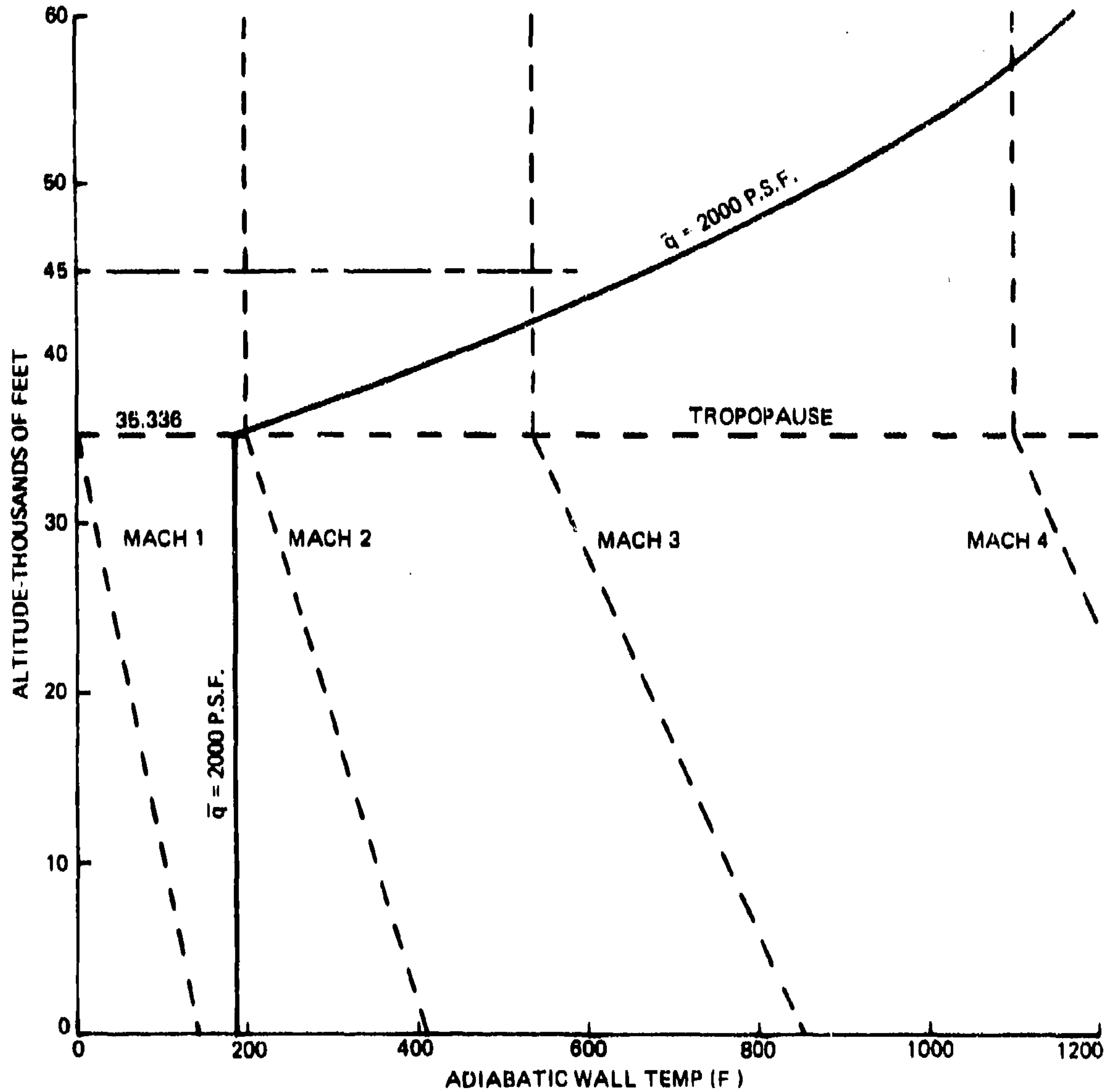
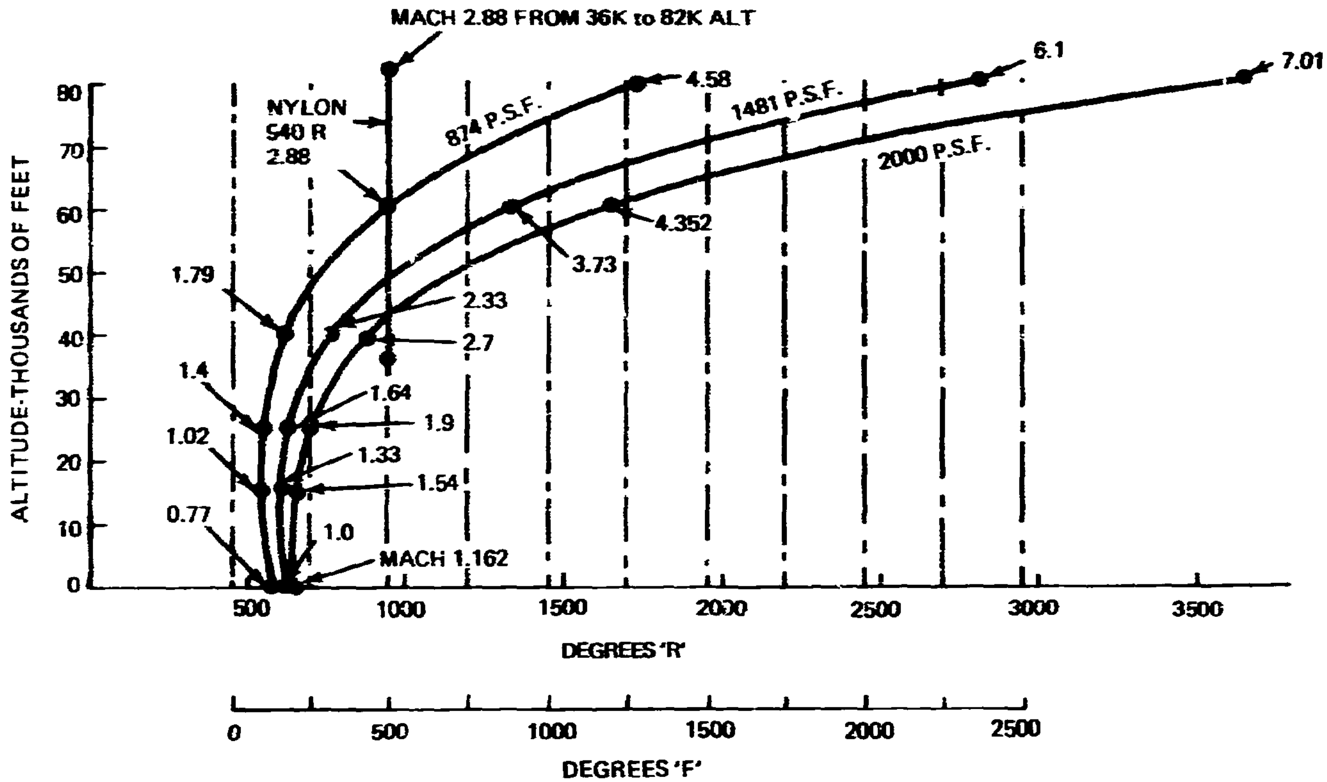


Figure 13 Adiabatic Wall Temperature for High $\bar{q}$ Escape System



SEE PAGE 449 OF REFERENCE (ASD-TR-61-579 '4469')

Figure 14 Mach No./Altitude/Temperature/q (P.S.F.)

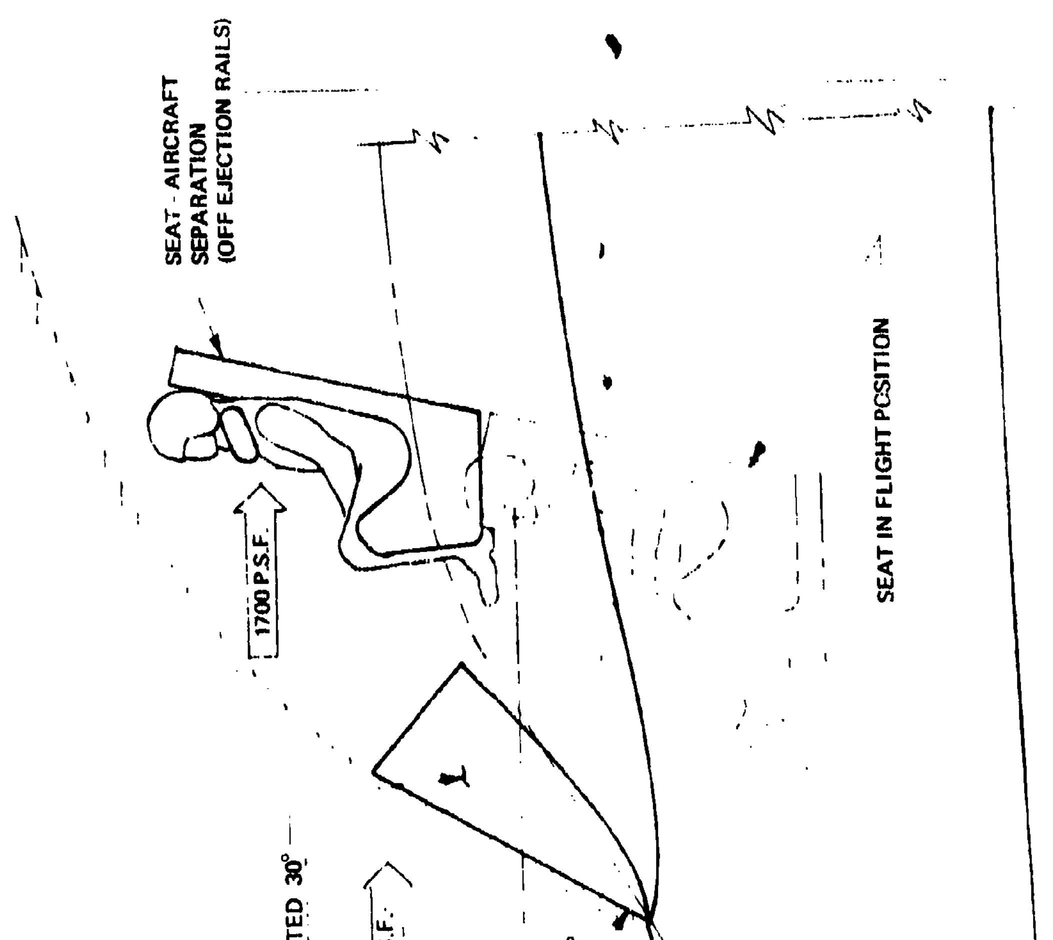


Figure 15 Windsplitter Configuration

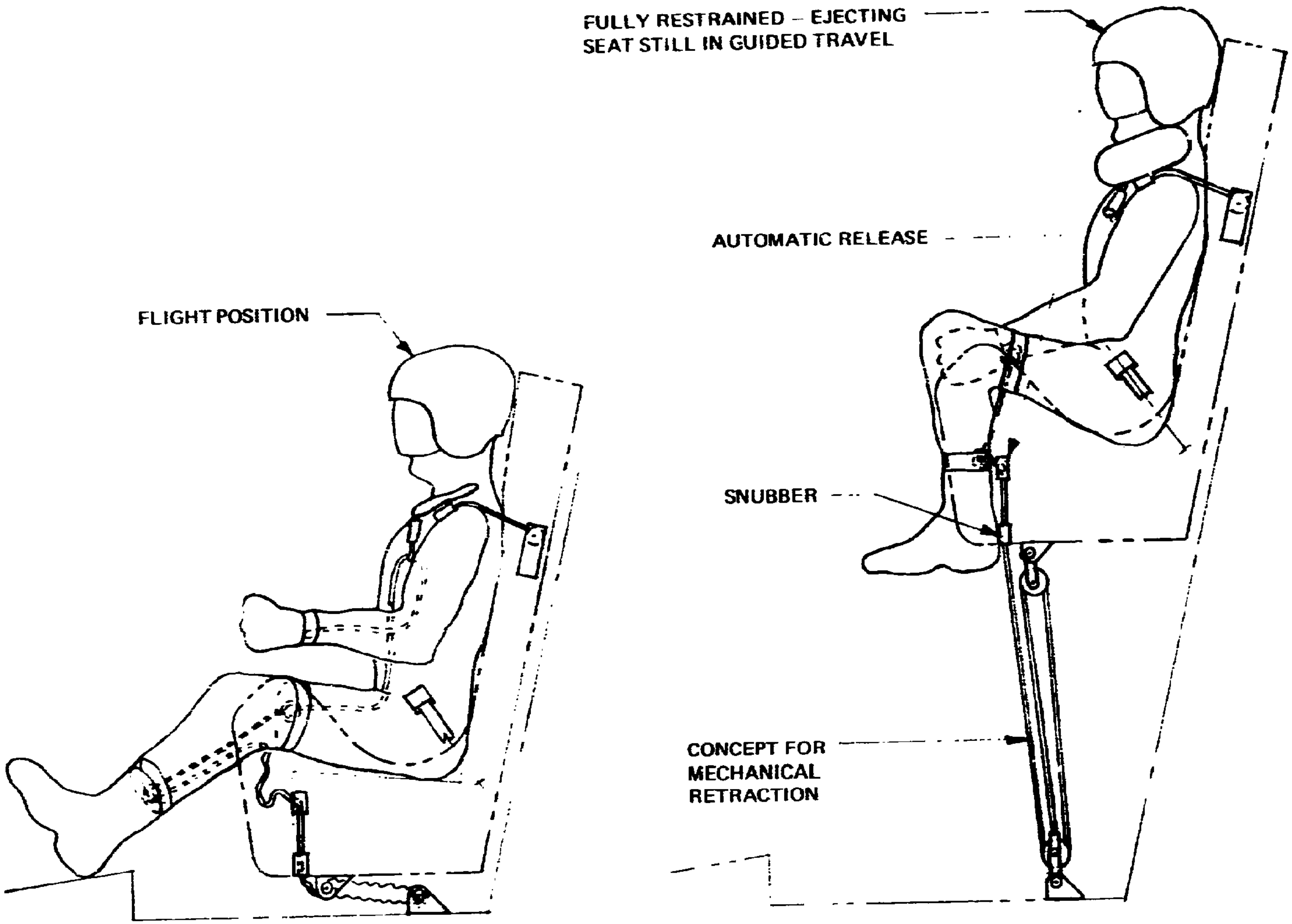


Figure 16 Datum Seat/Datum Concepts for 3 to 1 Mechanical Restraint Retraction

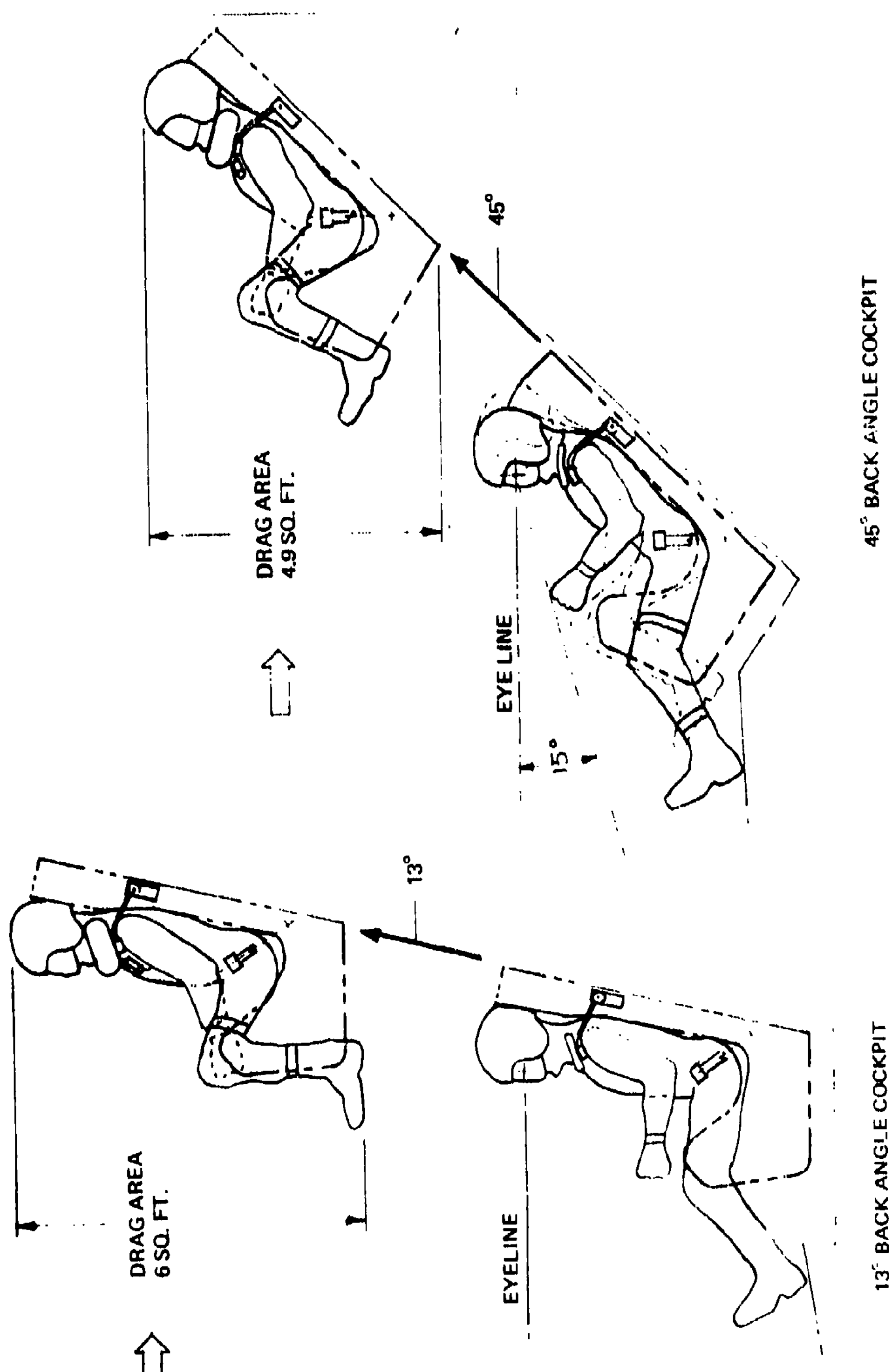
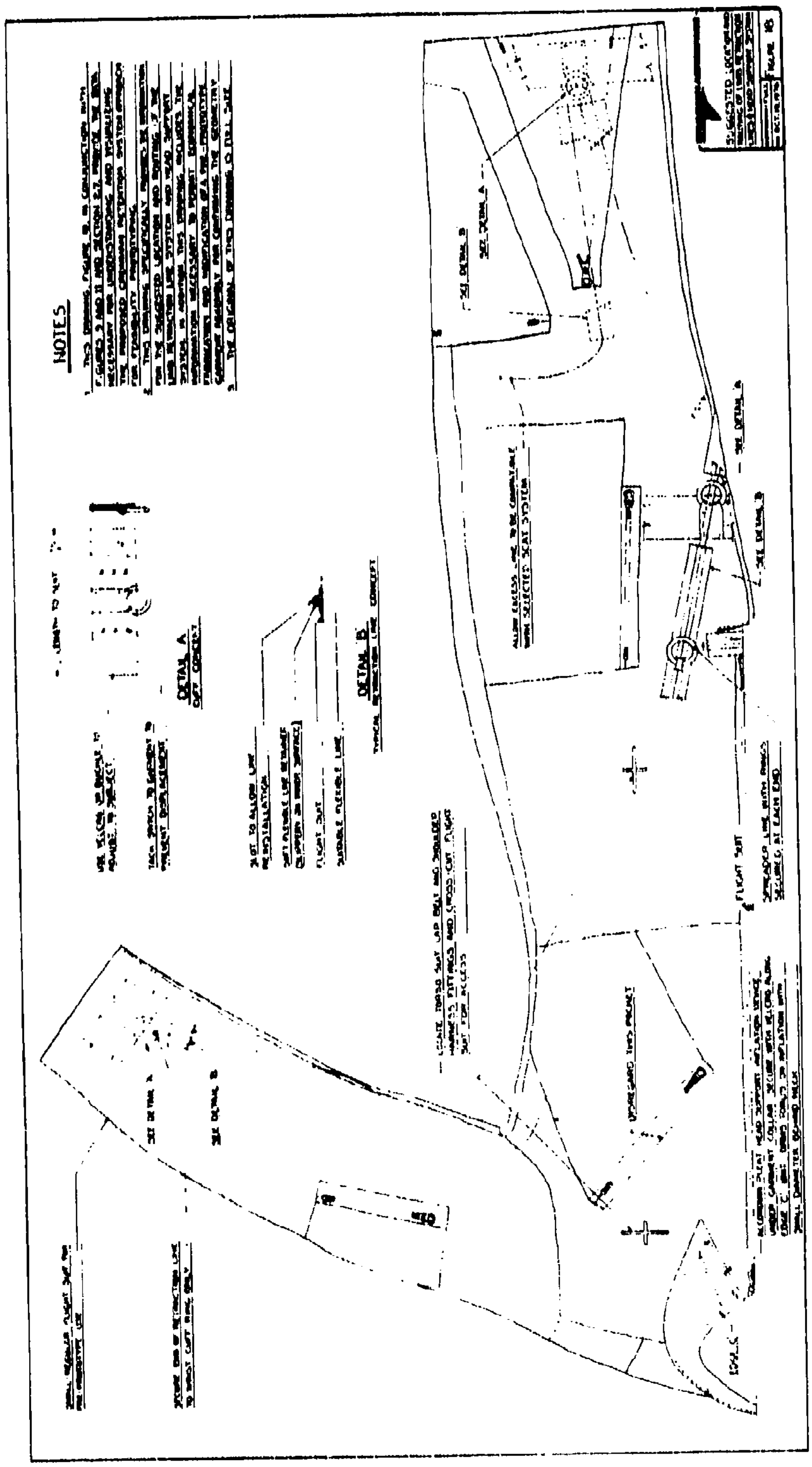


Figure 17 Datum Seat/13° and 45° Seat Back Angle Cockpit Ejection



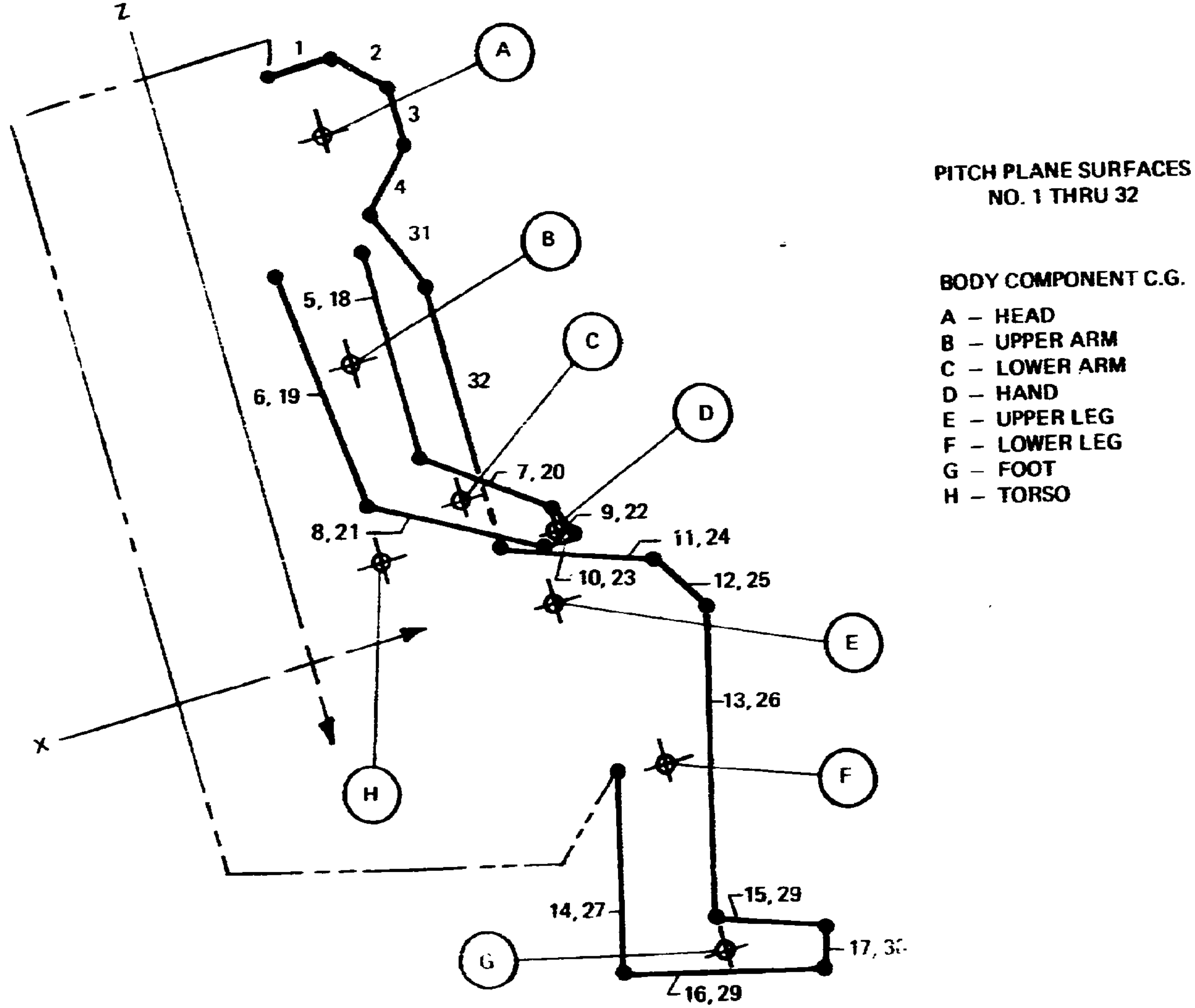


Figure 19 98th Percentile Man Model/Configuration 2

BODY MEMBER	PITCH PLANE REF.	MAX. P.S.F.	TIME-SEC.
TOP OF HEAD	1	749	.517
FOREHEAD	2	1081	.436
FRONT FACE	3	1155	.338
UNDER CHIN	4	880	.278
FRONT UPPER ARM	5	1137	.338
BACK UPPER ARM	6	111	1.02
FRONT LOWER ARM	7	1053	.472
BACK LOWER ARM	8	589	1.02
UPPER LEG	11	1009	.510
KNEE	12	1052	.406
SHIN	13	1181	.278
BACK LOWER LEG	14	5.5	1.02
TOP OF FOOT	15	989	.517
BOTTOM OF FOOT	16	601	1.05
TOE	17	1180	.278
UPPER CHEST	31	1103	.391
TORSO	32	1132	.338

Figure 20 – Table of Maximum P.S.F. 600 Kts Sea Level -- Configuration 2

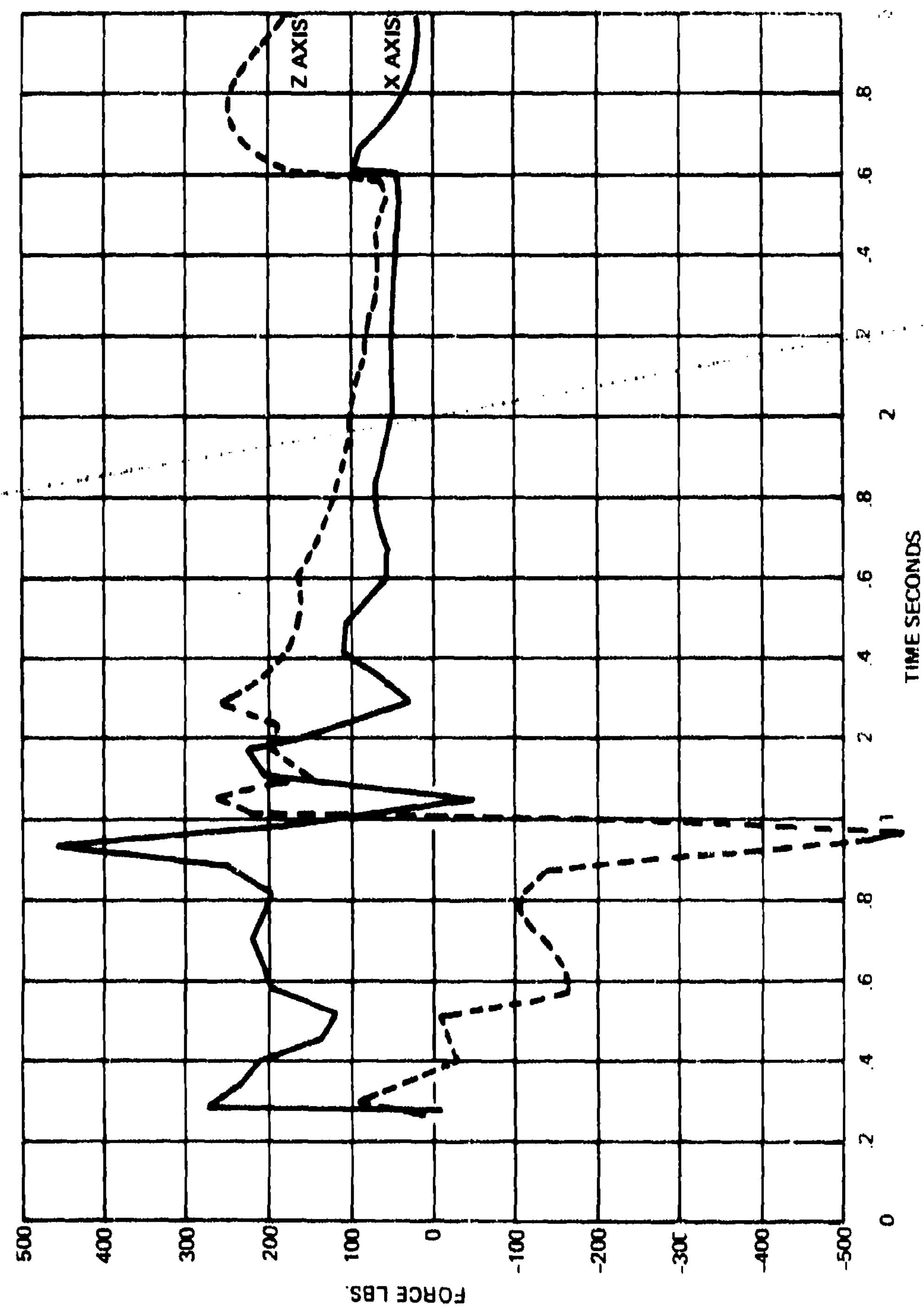


Figure 21 Head Acceleration Forces/600 KTS. Sea Level Configuration 2

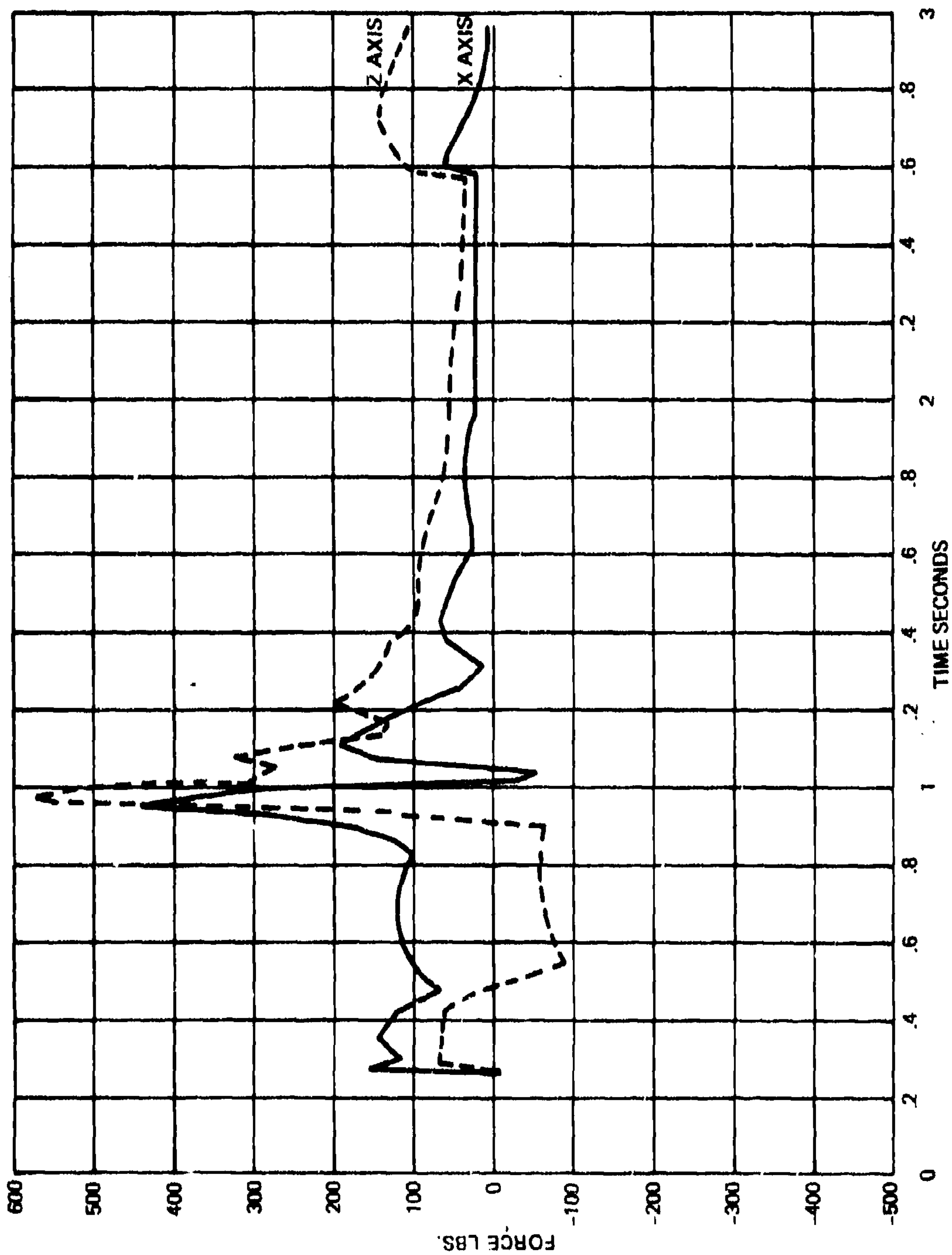


Figure 22 LWR. Leg Acceleration Forces/600 Kts Sea Level Configuration 2

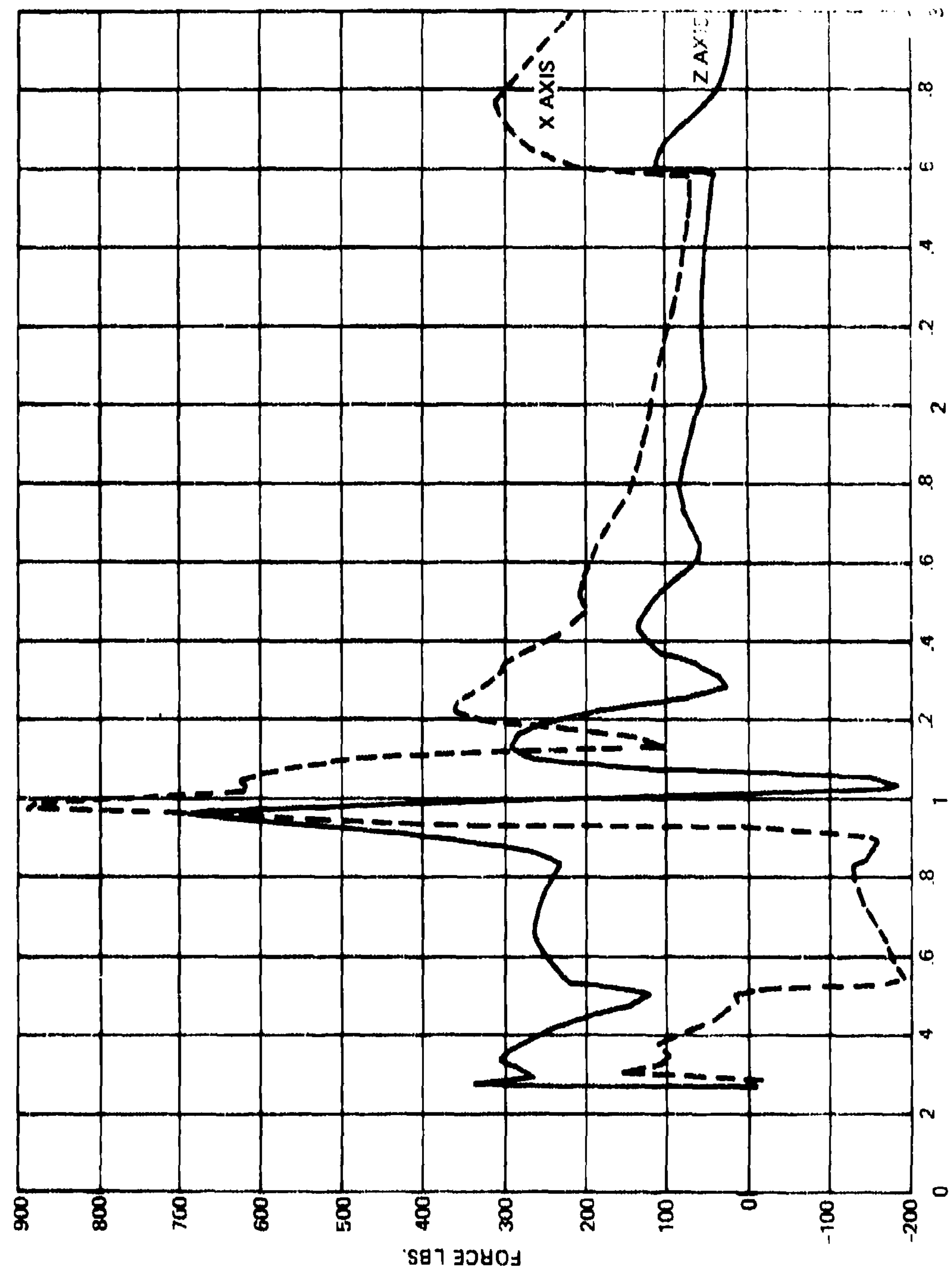
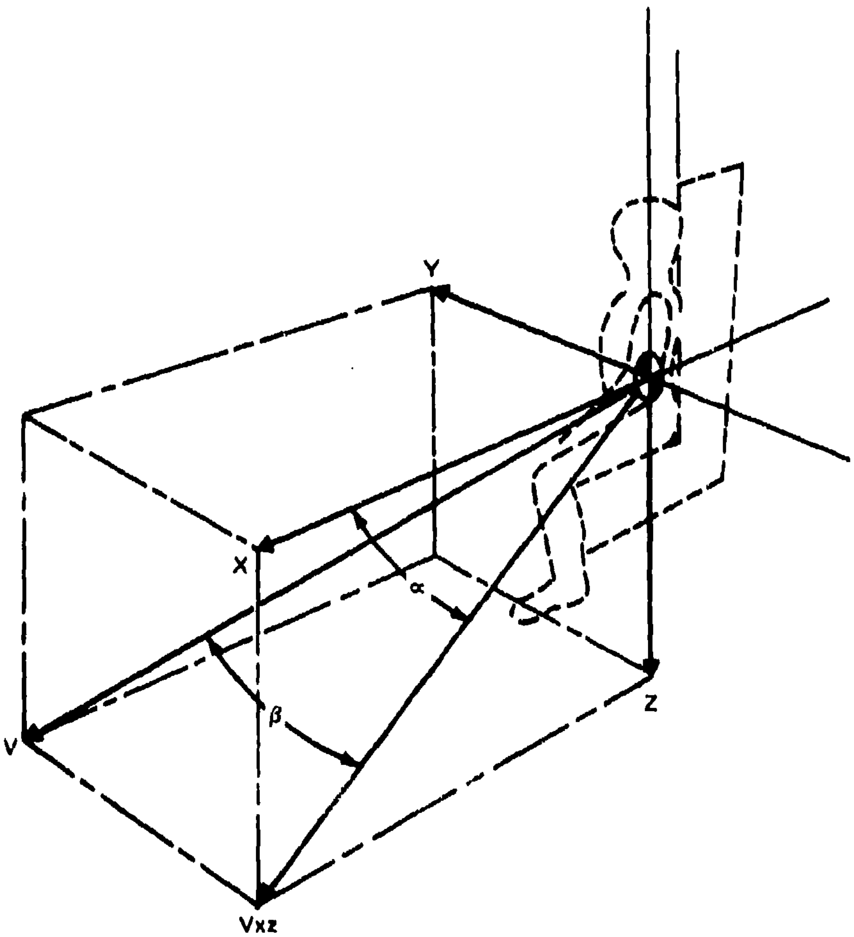


Figure 23 Upper Leg Acceleration Forces/600 KTS Sea Level Configuration 2



- ALPHA (α), THE SEAT/MAN ANGLE OF ATTACK, IS THE ANGLE BETWEEN THE X-BODY AXIS AND THE COMPONENT OF THE VELOCITY VECTOR IN THE X-Z PLANE, Vxz.
- BETA (β), THE SEAT/MAN ANGLE OF SIDESLIP, IS THE ANGLE BETWEEN THE X-Z PLANE AND THE TOTAL VELOCITY VECTOR, V.

Figure 24 Alpha Beta Angle Definition

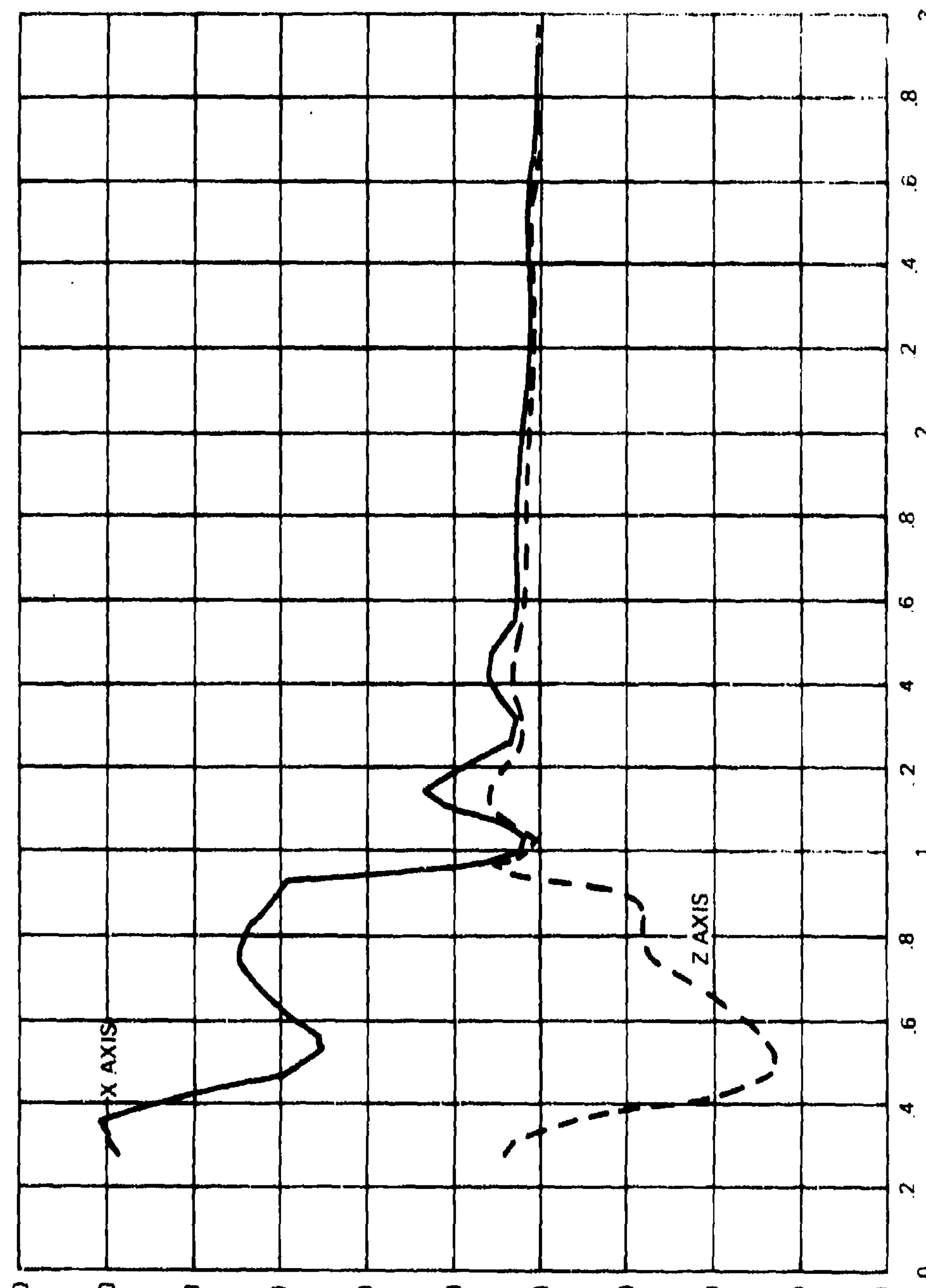


Figure 25 Head Wind Blast Forces/600 KTS Sea Level Configuration 2

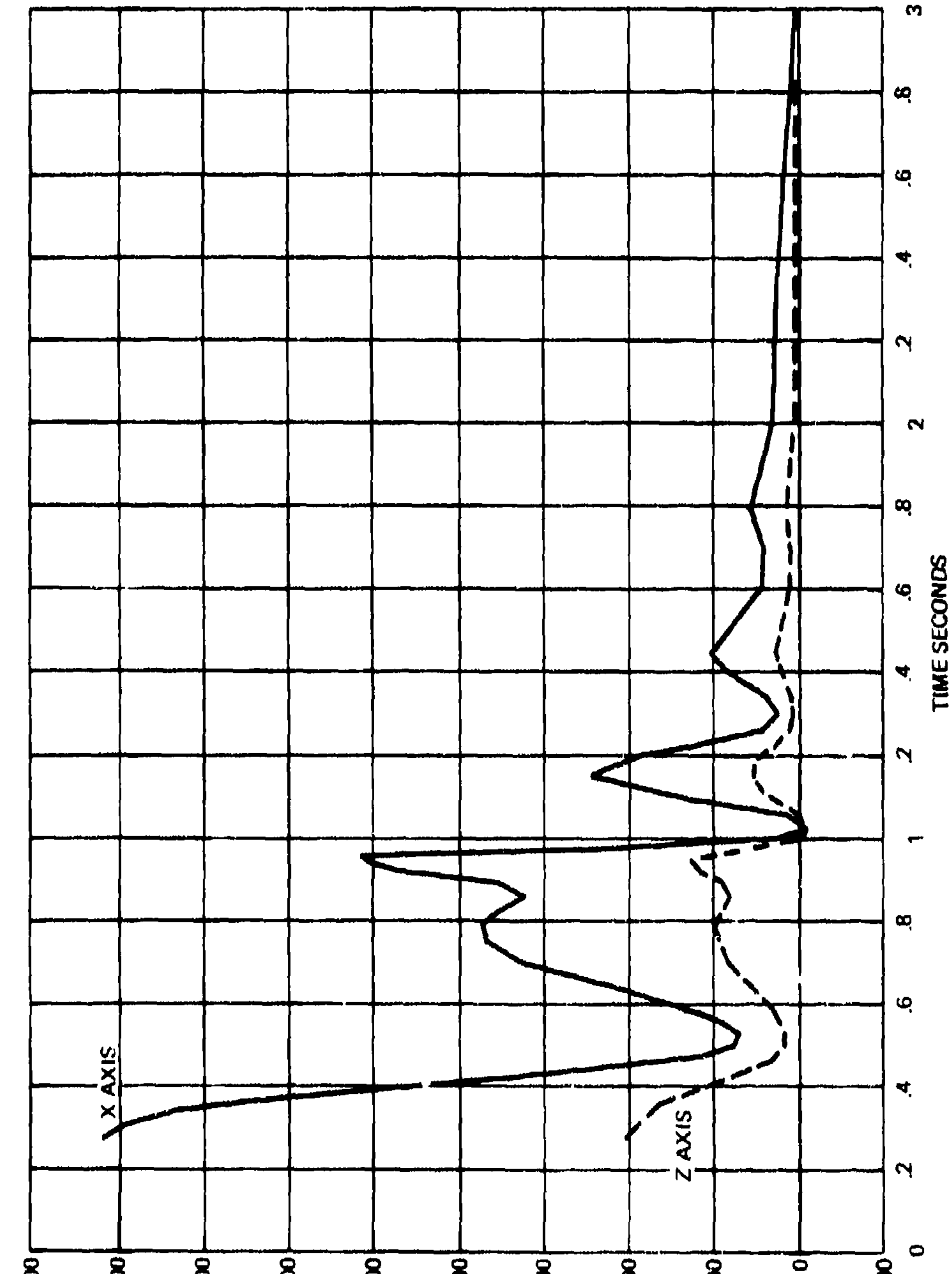


Figure 26 Lower Leg Wind Blast Forces/600 KTS Sea Level Configuration 2

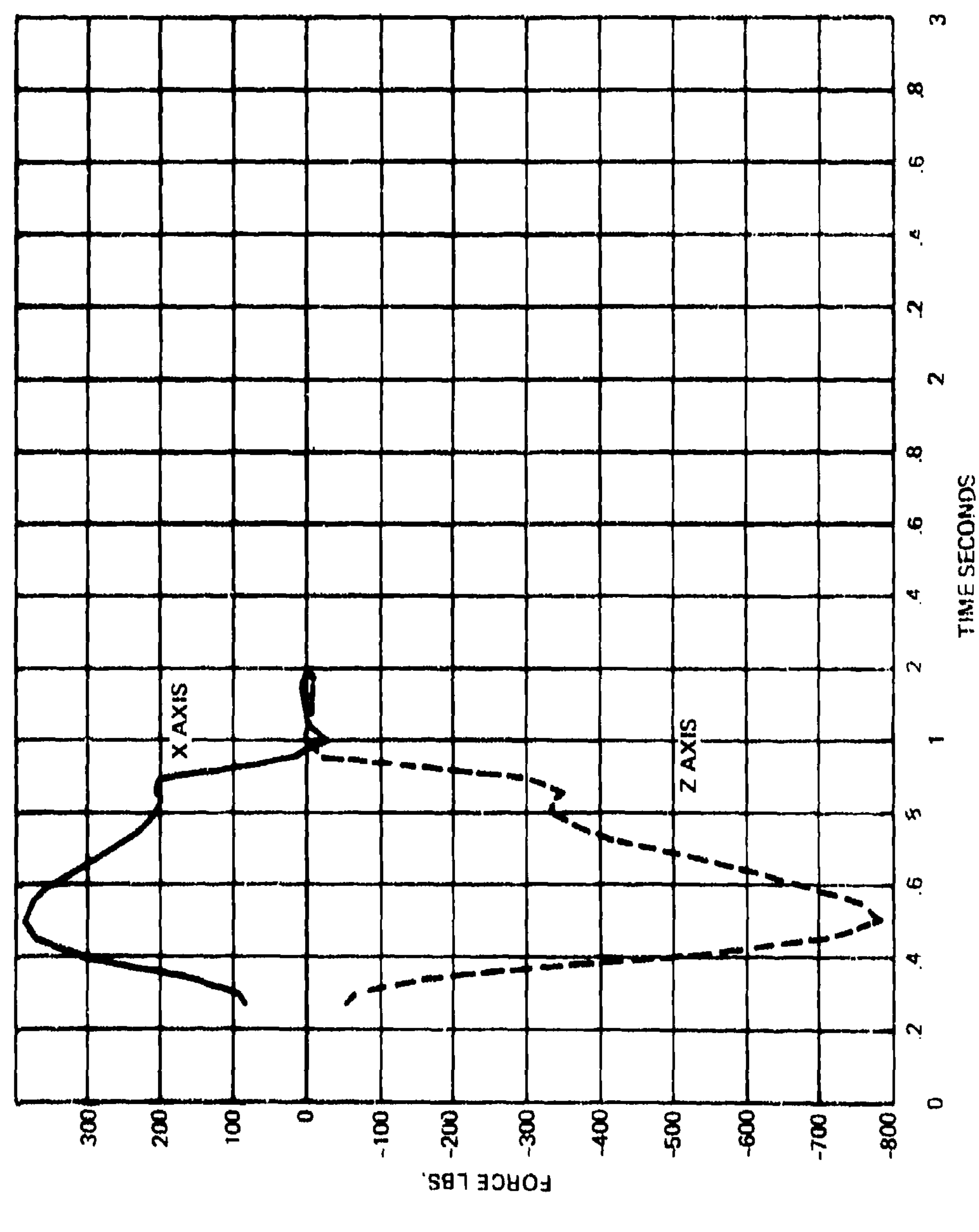


Figure 27 Upper Leg Wind Blast Forces/600 KTS Sea Level Configuration 2

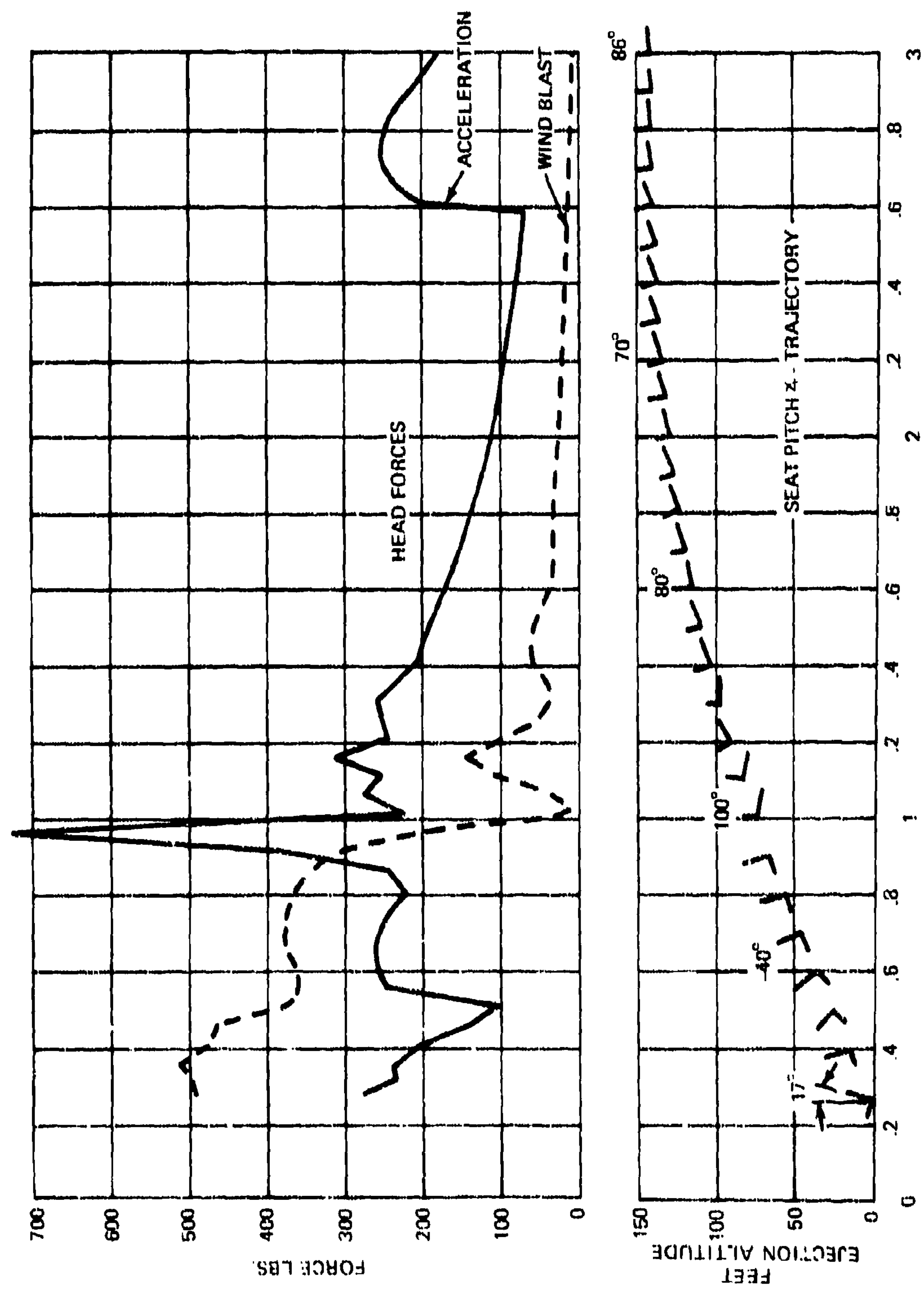


Figure 28 Head Forces/Seat Pitch ∡ - Trajectory/600 KTS. Configuration 2

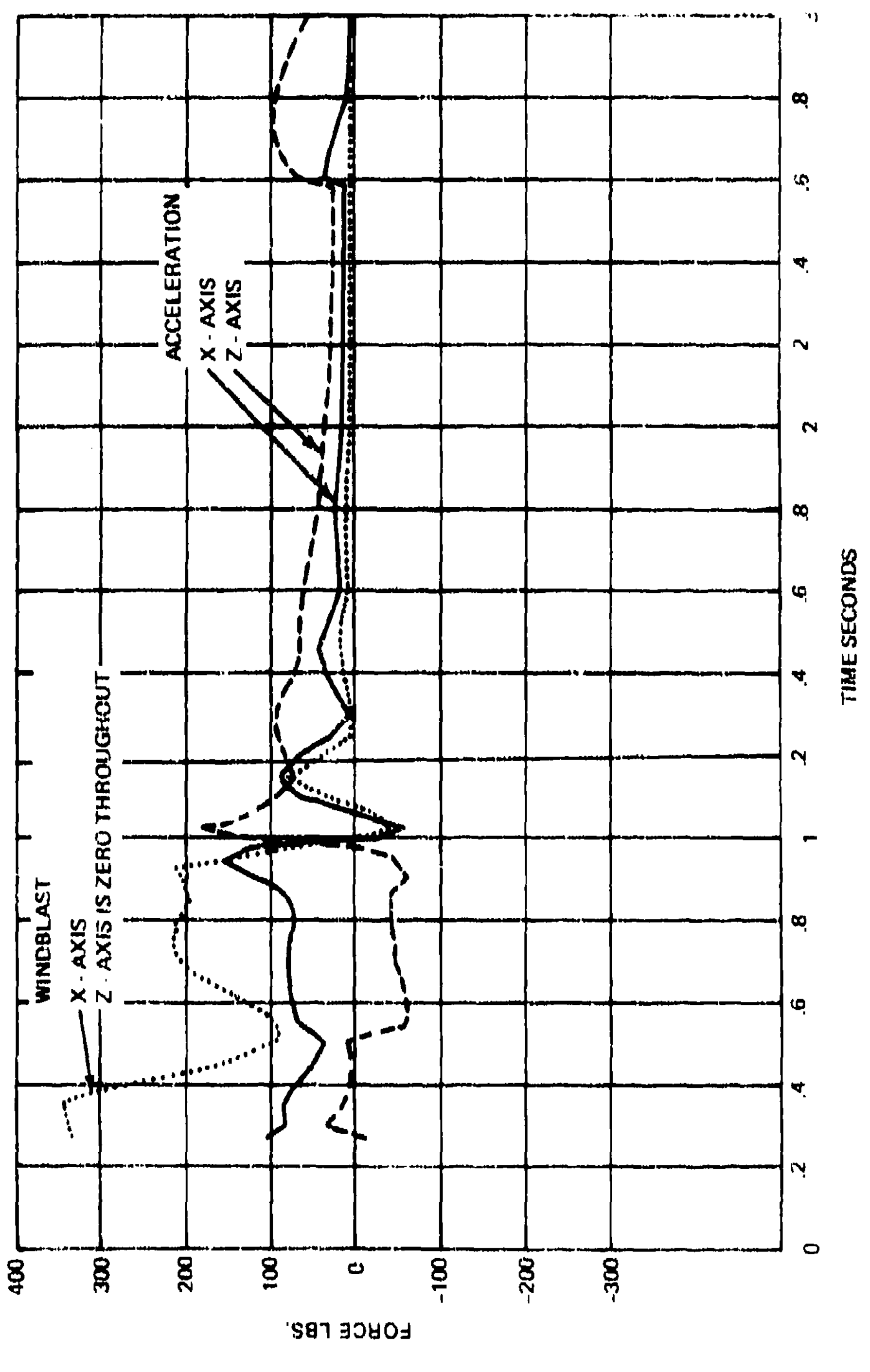


Figure 29 Upper Arm Forces/600 KTS Sea Level Configuration 2

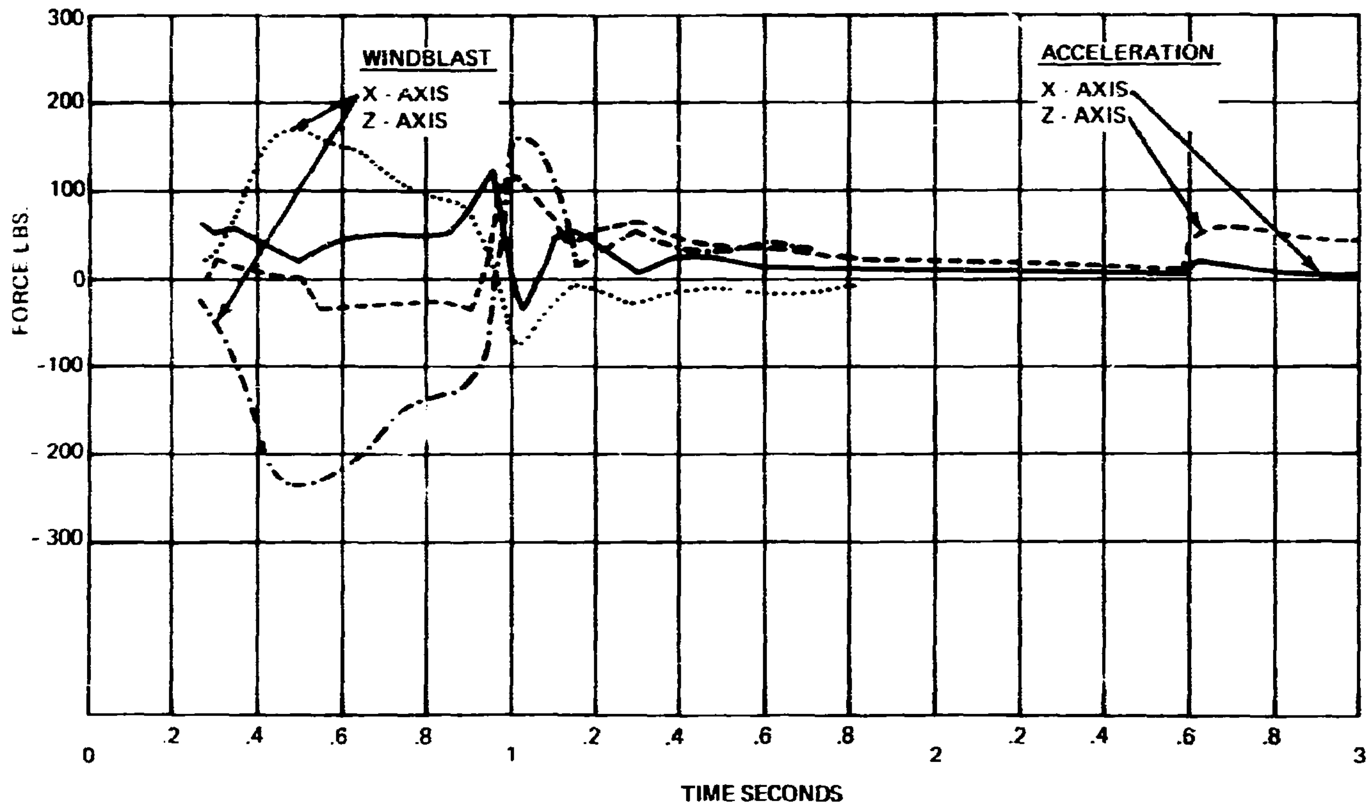


Figure 30 Lower Arm Forces/600 KTS. Sea Level Configuration 2

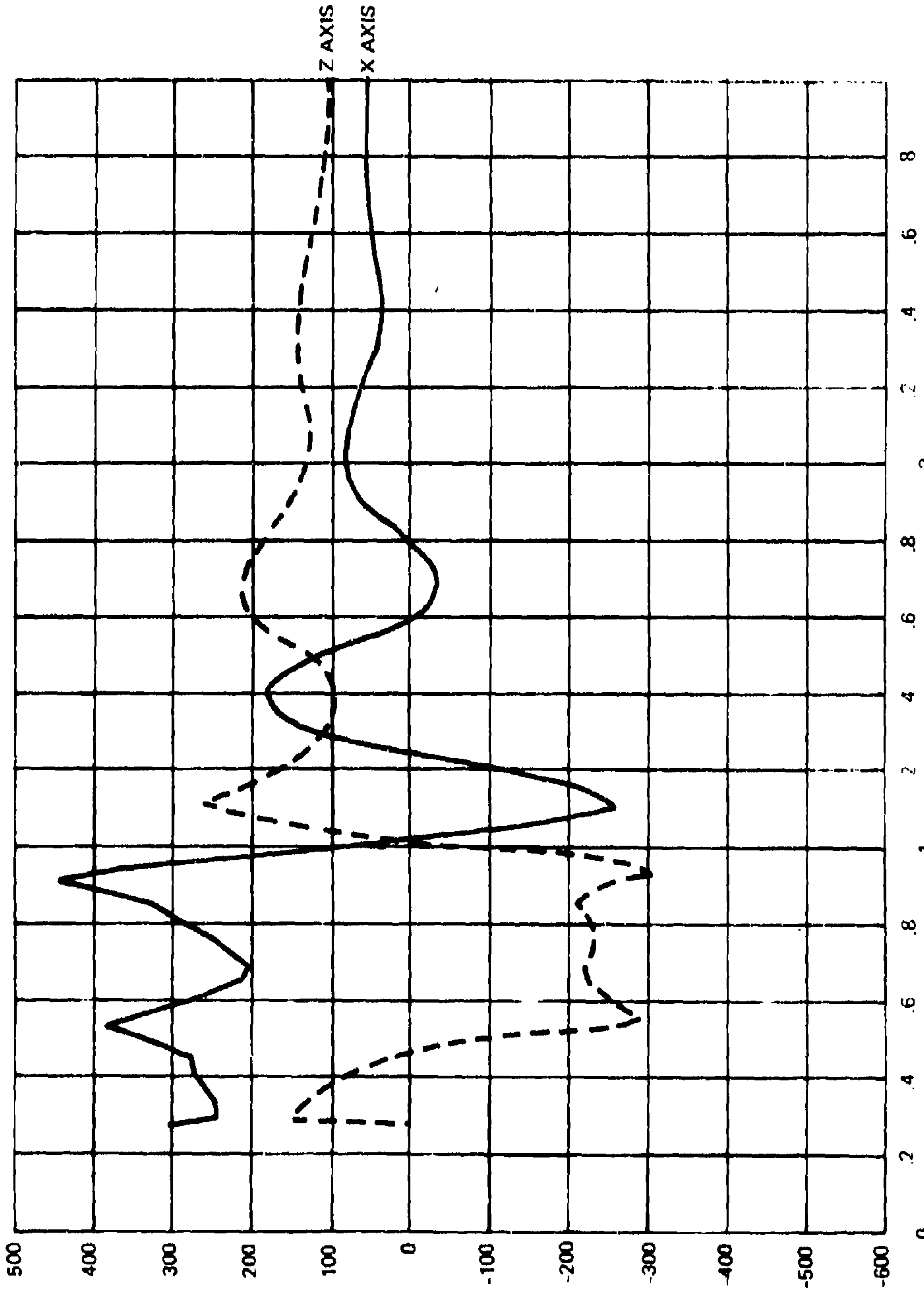


Figure 31 Head Acceleration Forces/1365 KTS 45K Ft. Configuration 2

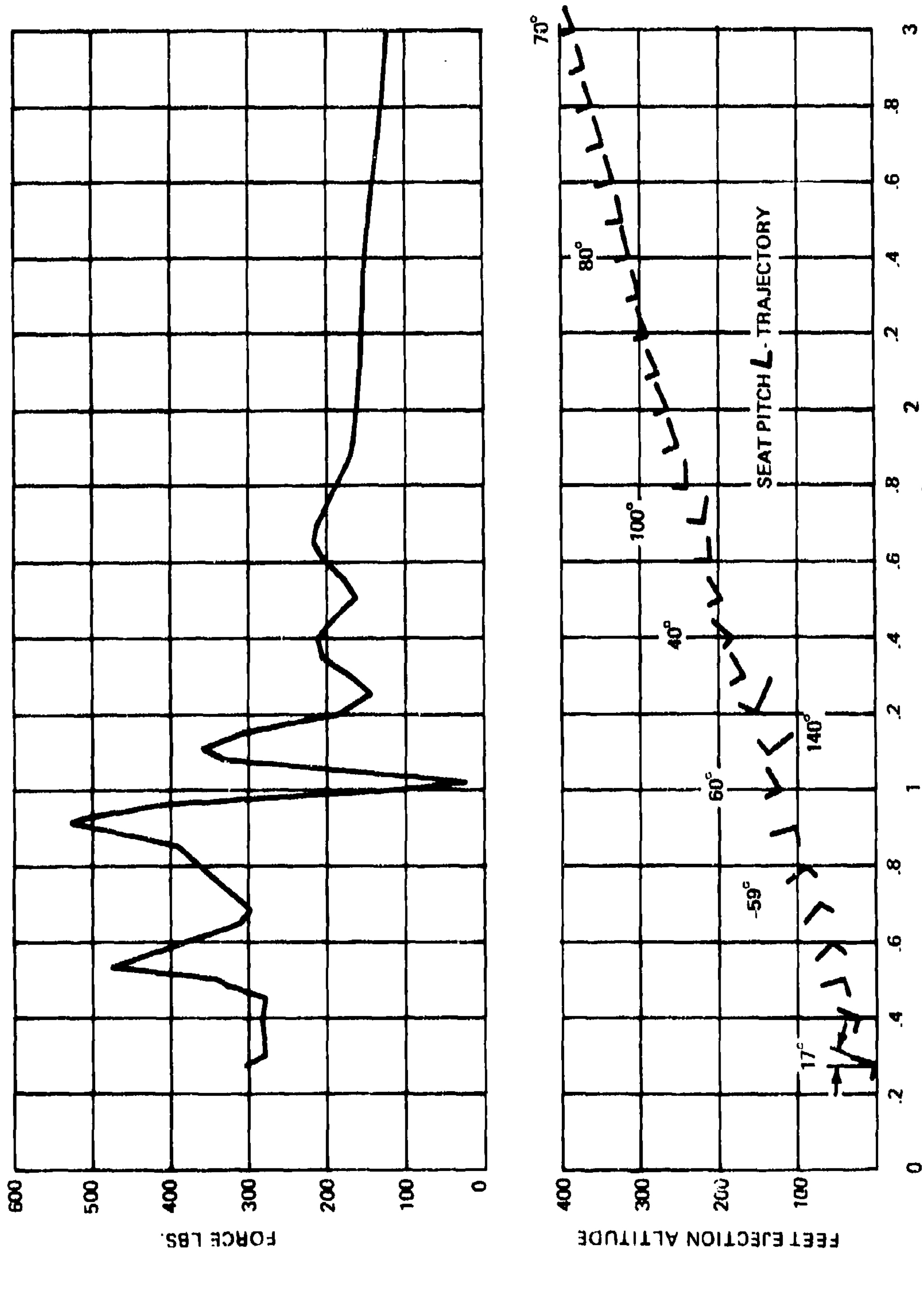


Figure 32 Head Forces/Seat Pitch ∠ - Trajectory 1365 KTS. 45K FT. Altitude Configuration 2

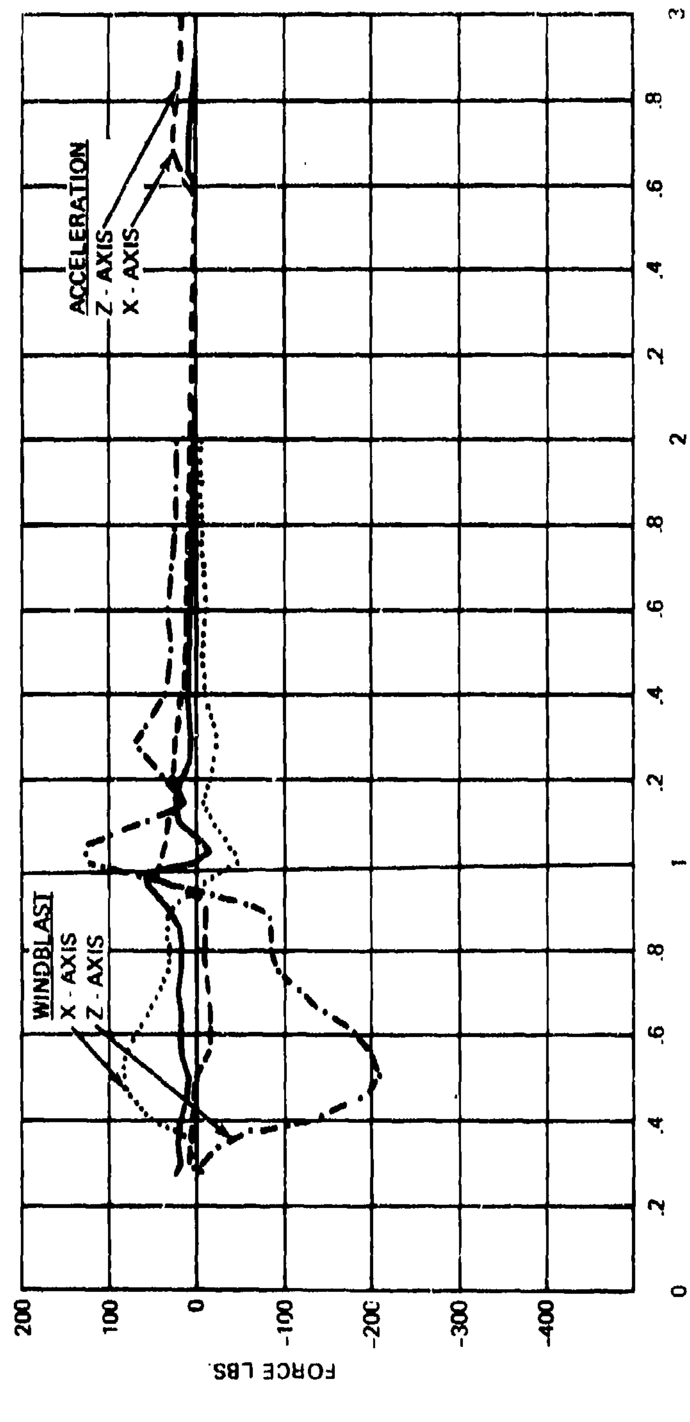


Figure 33 Hand Forces/600 KTS. Sea Level Configuration 2

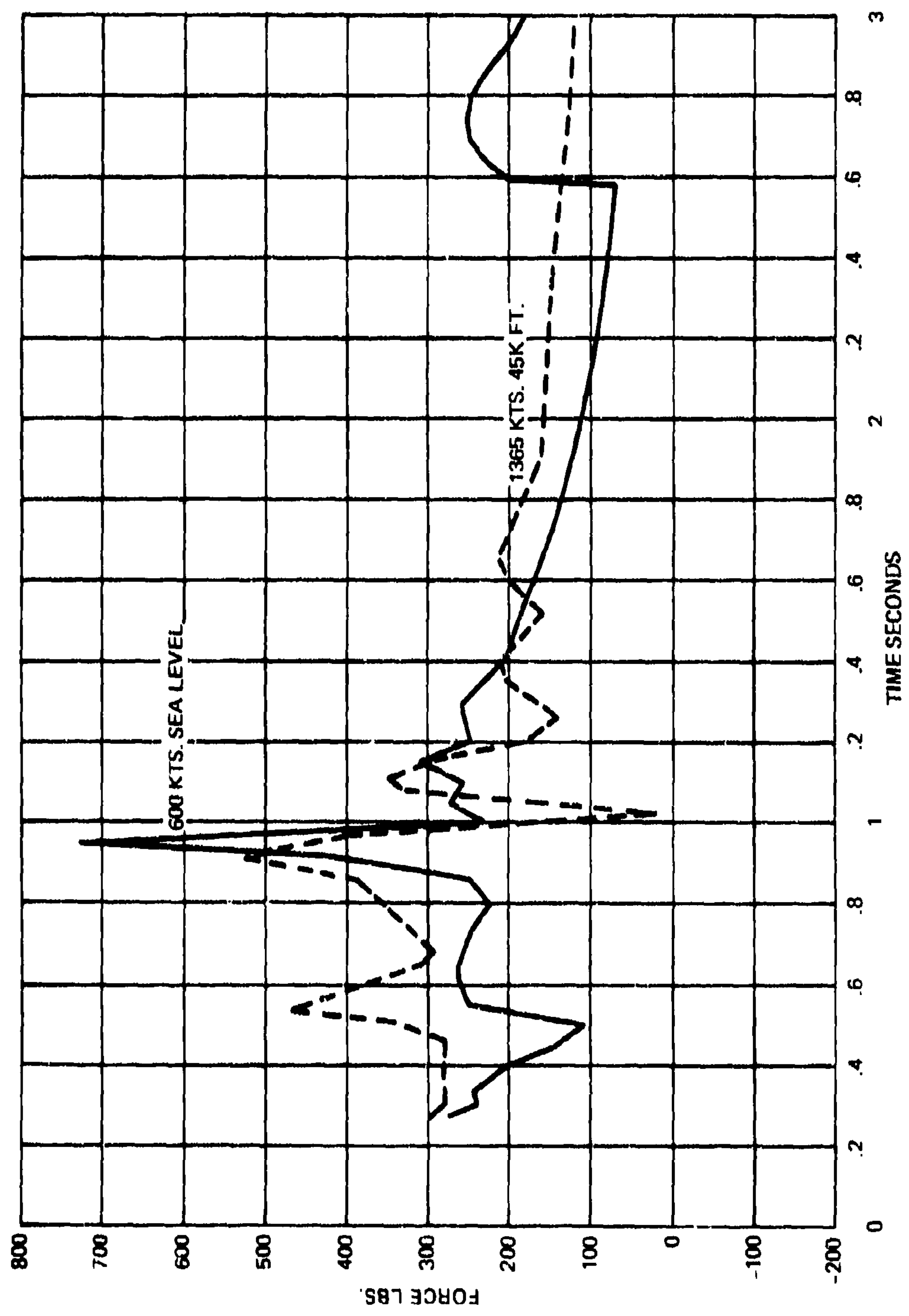


Figure 34 Head Force Comparison For 1220 P.S.F./Sea Level & 45K Ft. Configuration 2

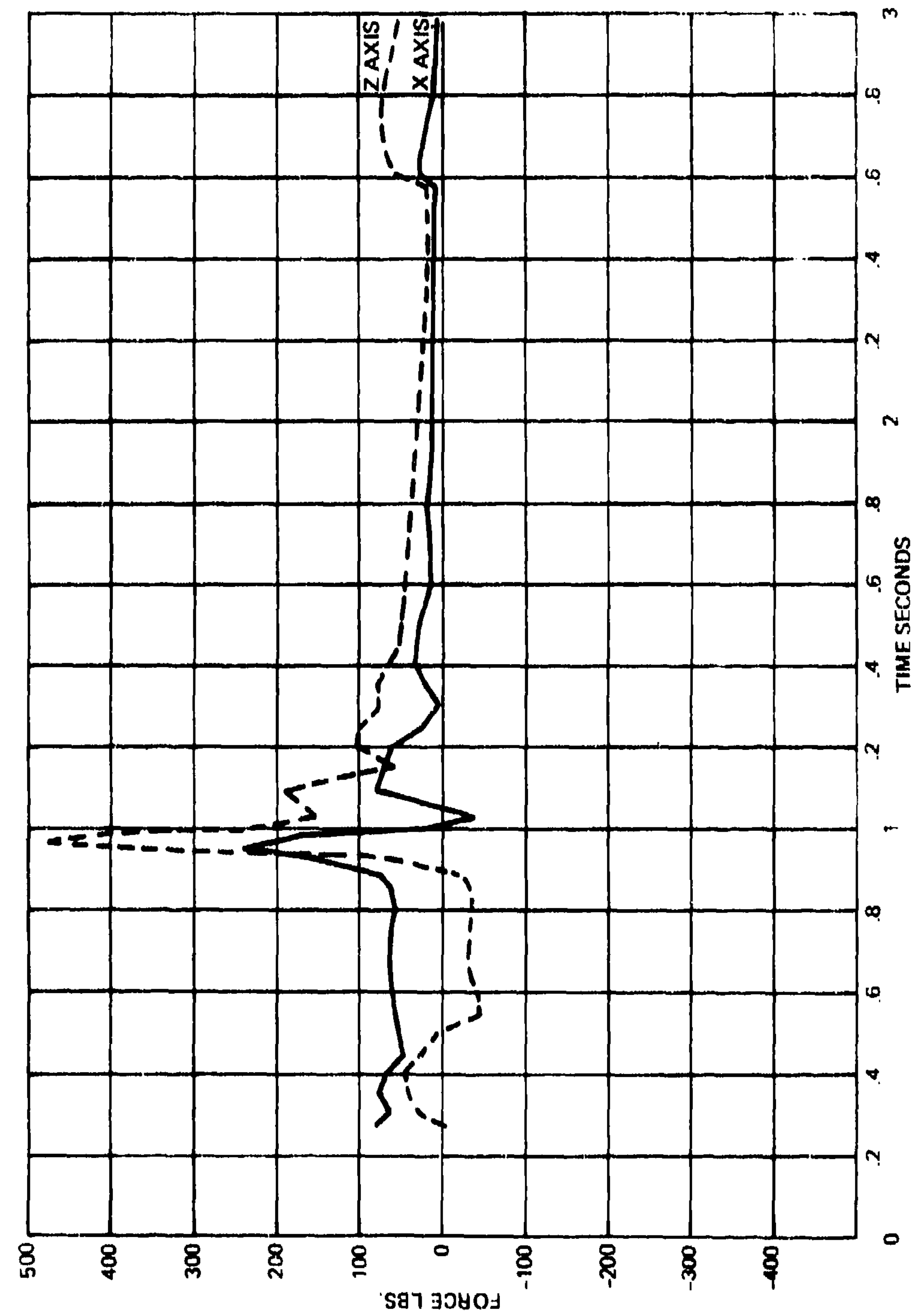


Figure 35 Foot Acceleration Forces/600 KTS. Sea Level Configuration 2

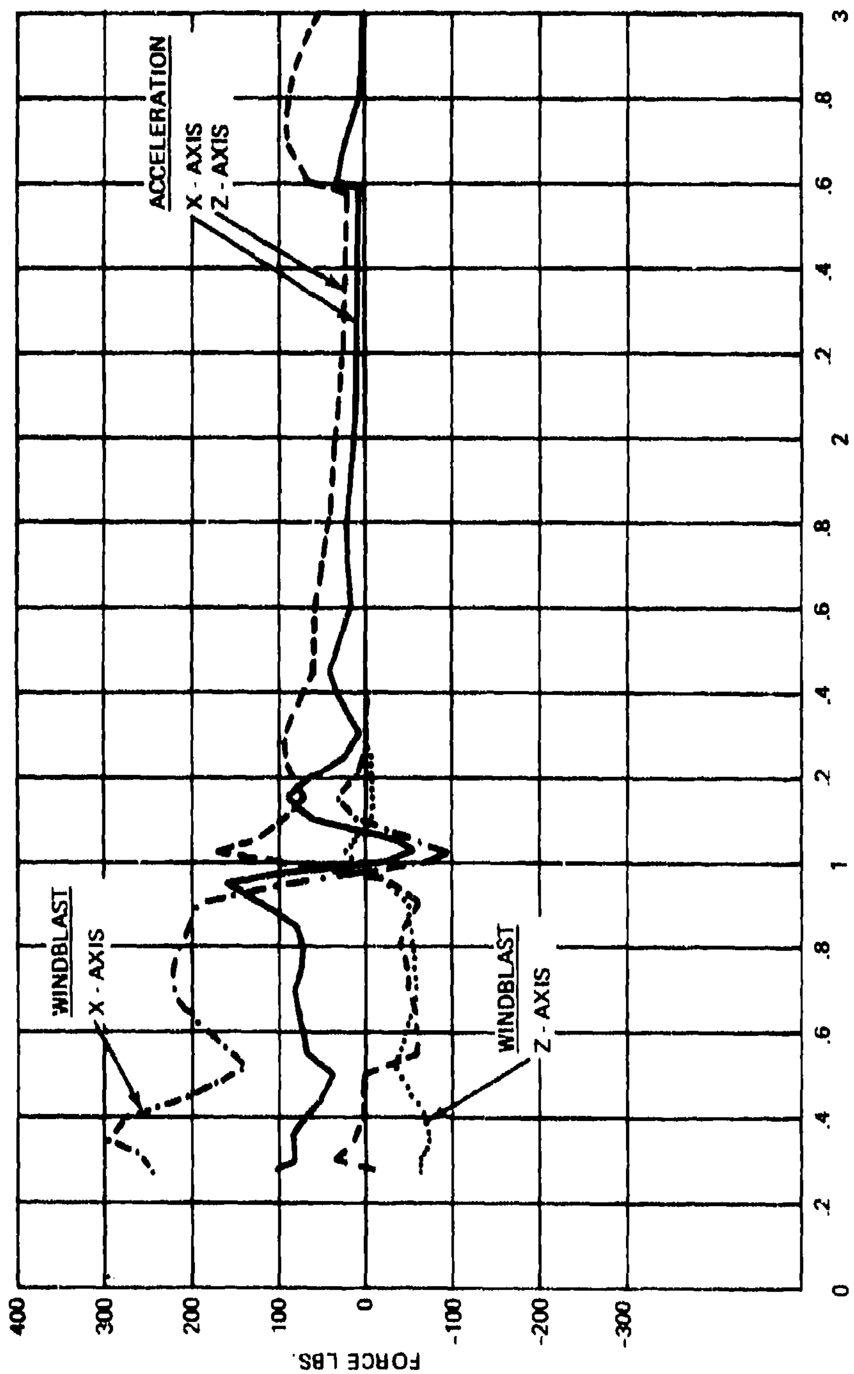


Figure 36 Upper Arm Forces/600 KTS Sea Level Configuration 1

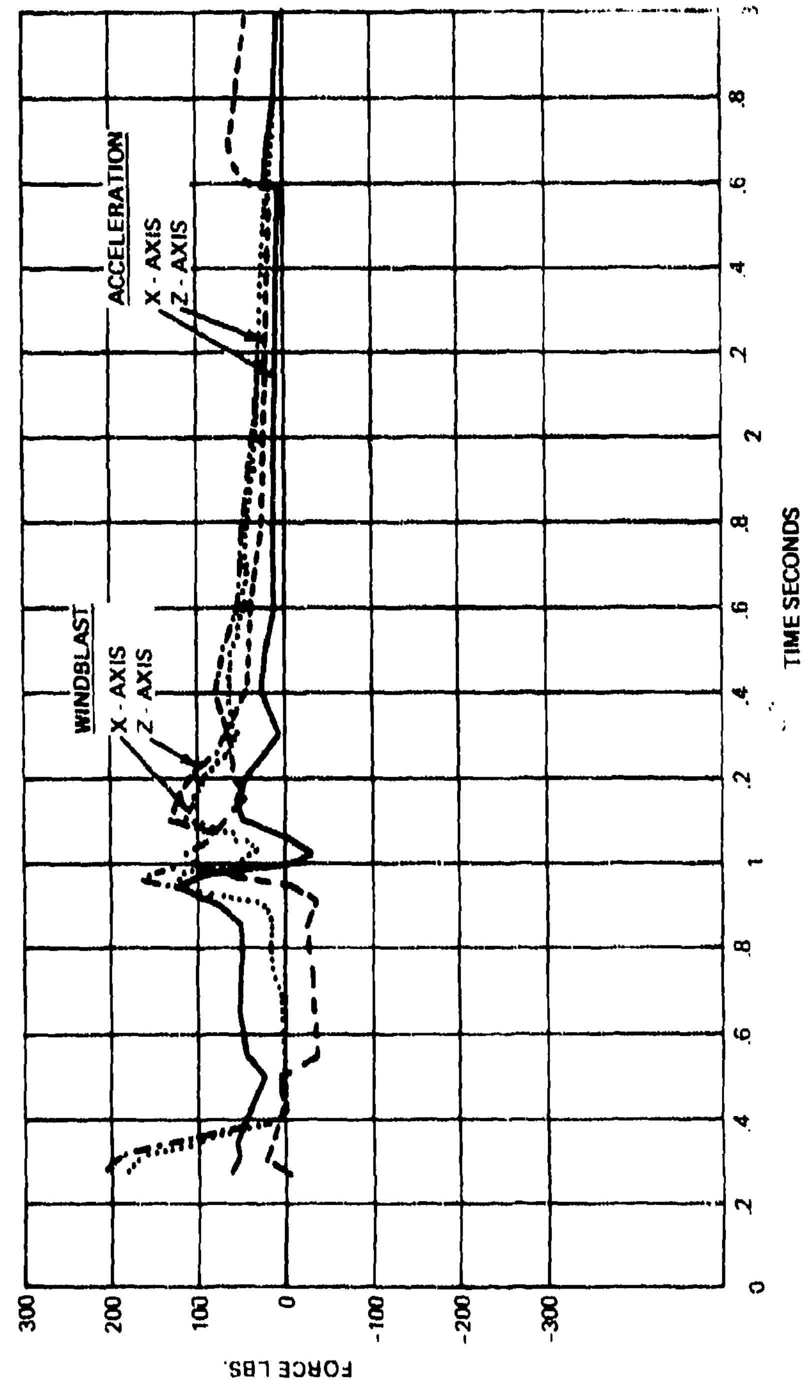


Figure 37 Lower Arm Forces/600 KTS Sea Level Configuration

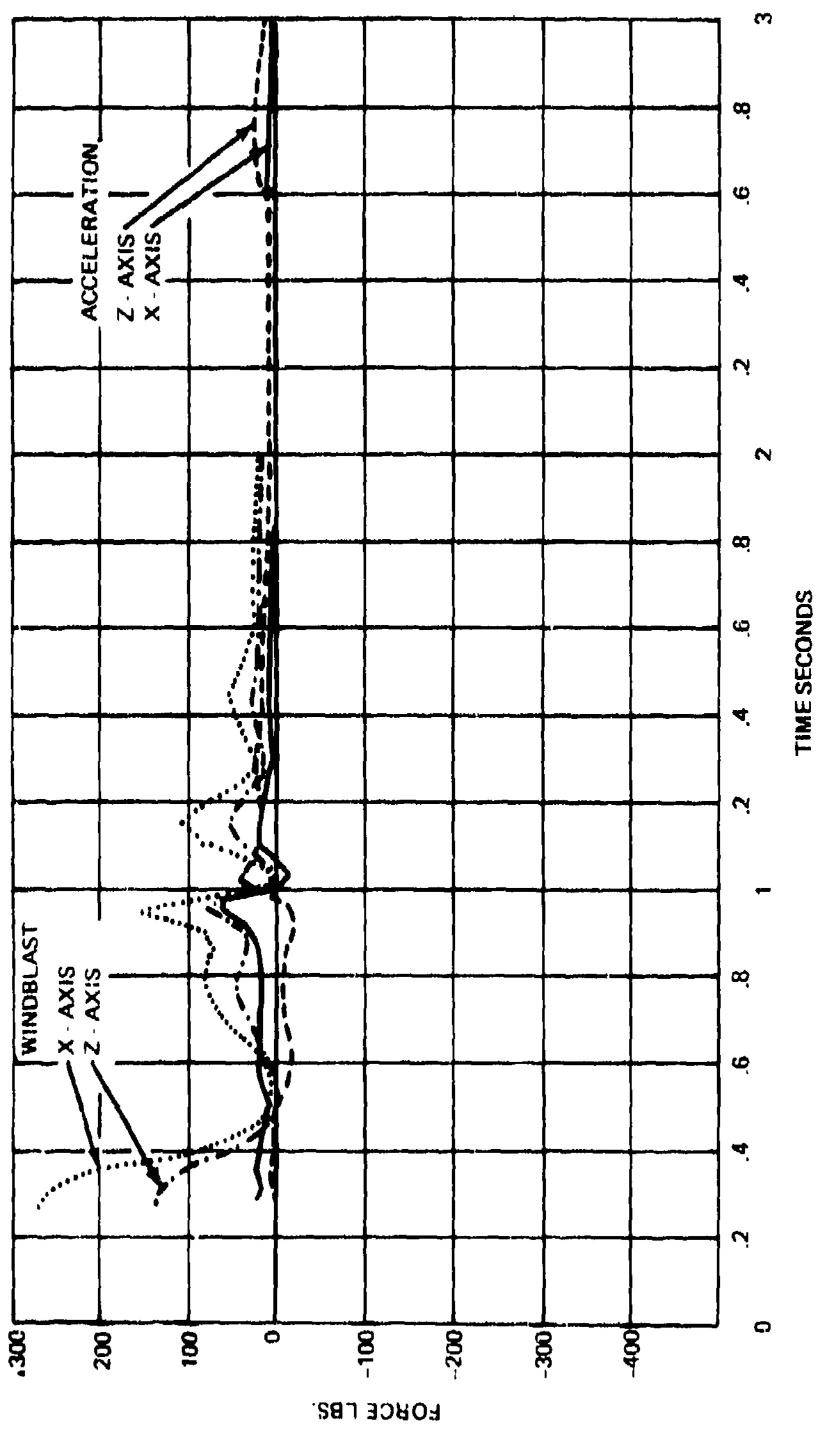


Figure 38 Hand Forces/600 KTS Sea Level Configuration 1

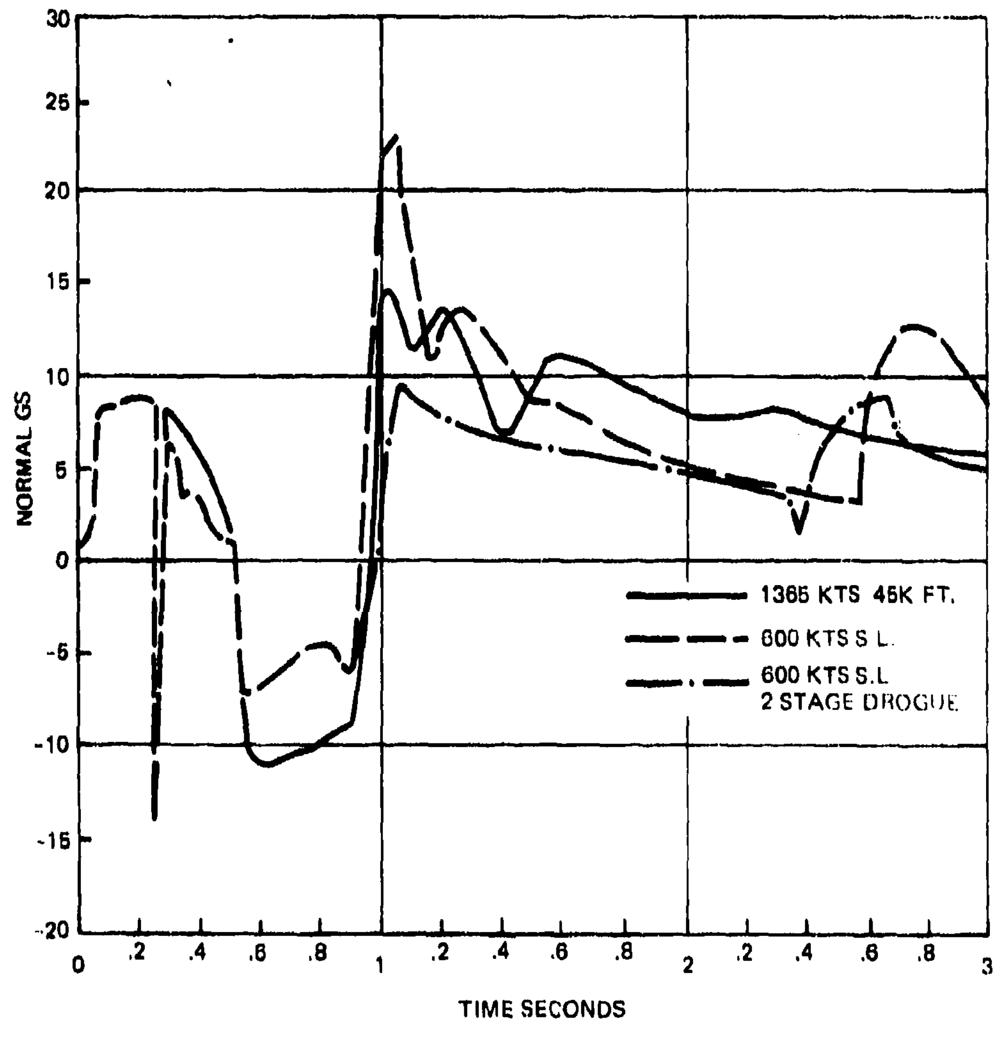


Figure 39 Normal 'G' Comparison for Ejection at 1220 P.S.F. at Sea Level & 45K Ft.

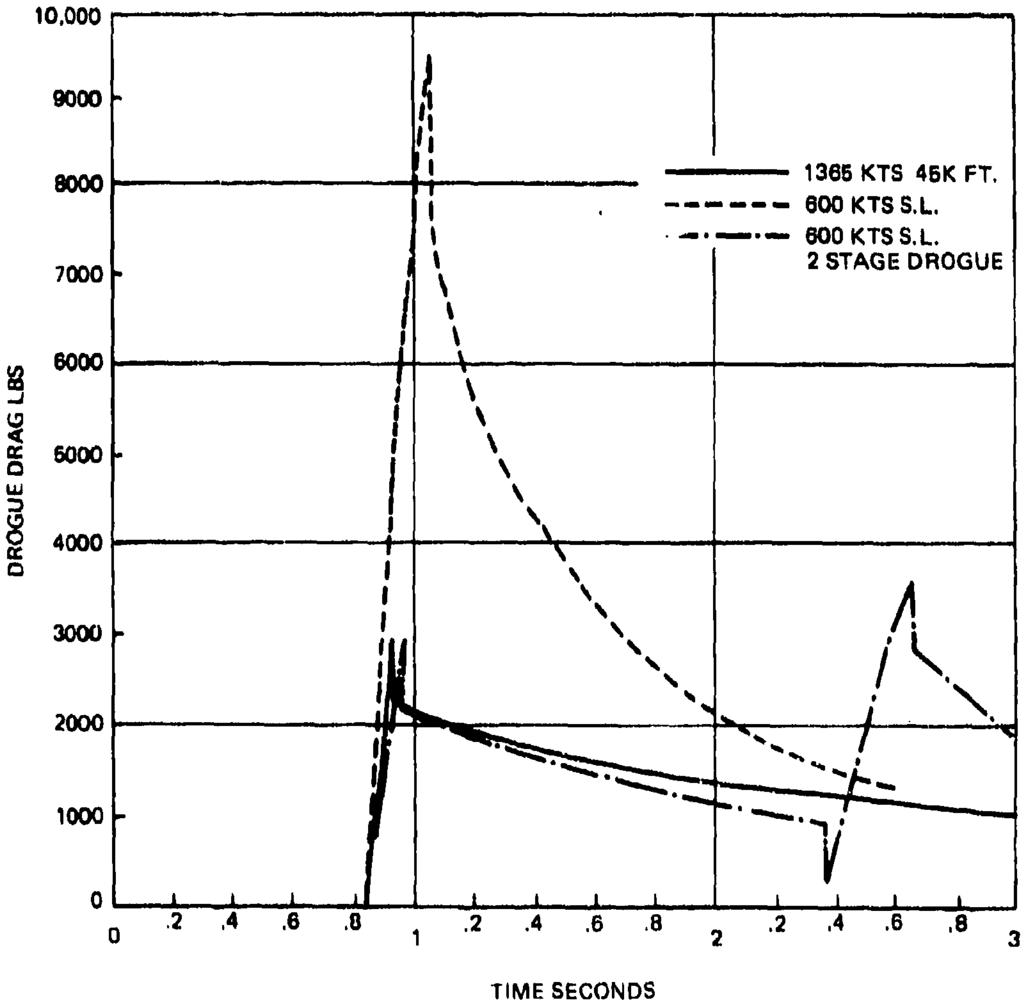


Figure 40 Drogue Drag Comparison For Ejection at 1220 P.S.F. at Sea Level & 45K Ft.

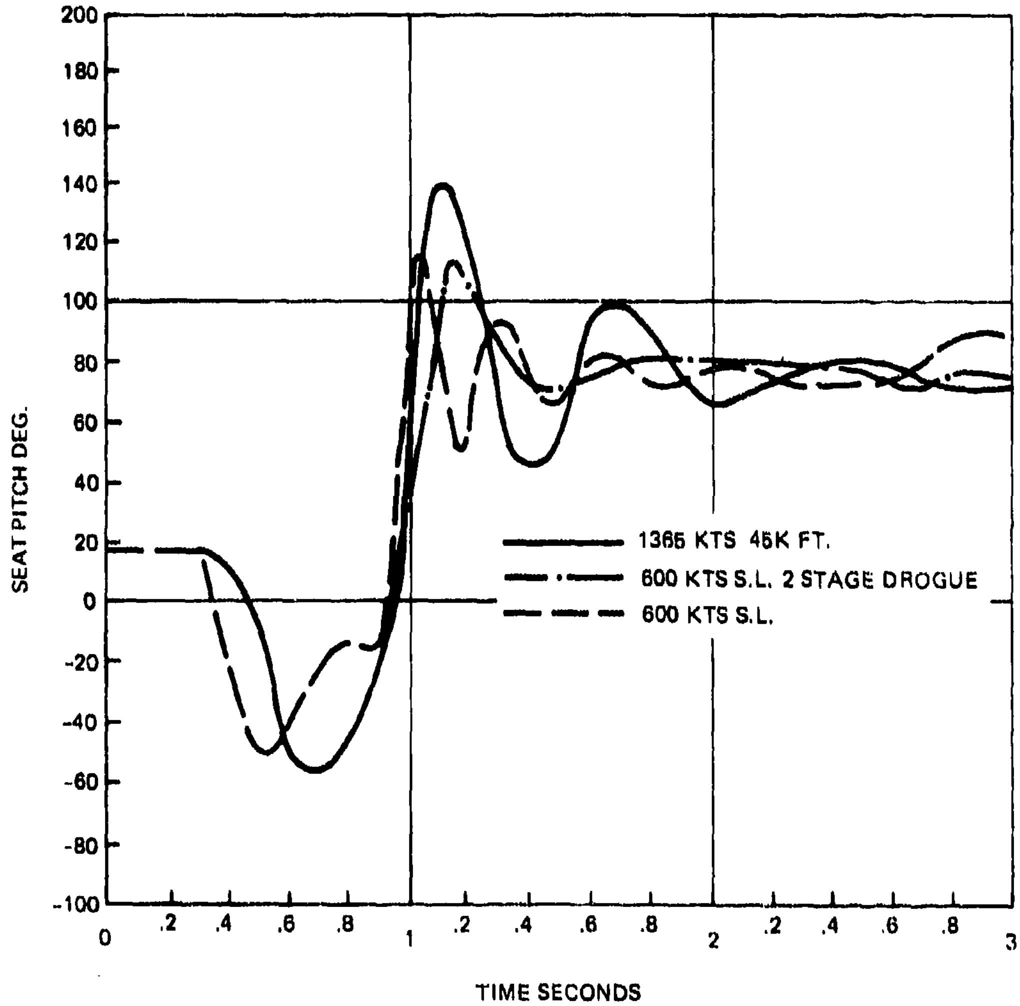


Figure 41 Seat Pitch Degree Comparison for Ejection at 1220 P.S.F. at Sea Level & 45K Ft.

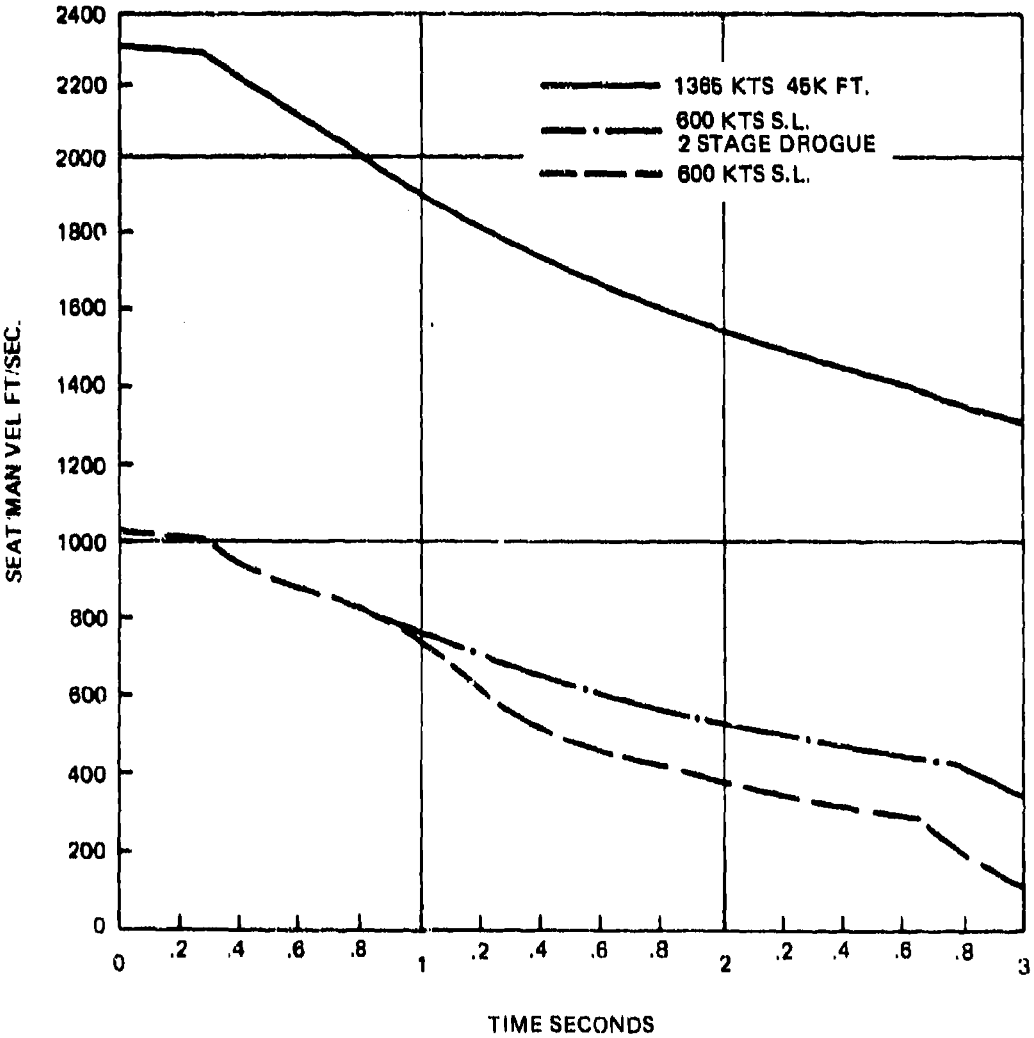


Figure 42 Seat/Man Velocity Comparison for Ejection at 1220 P.S.F. at Sea Level & 45K Ft.

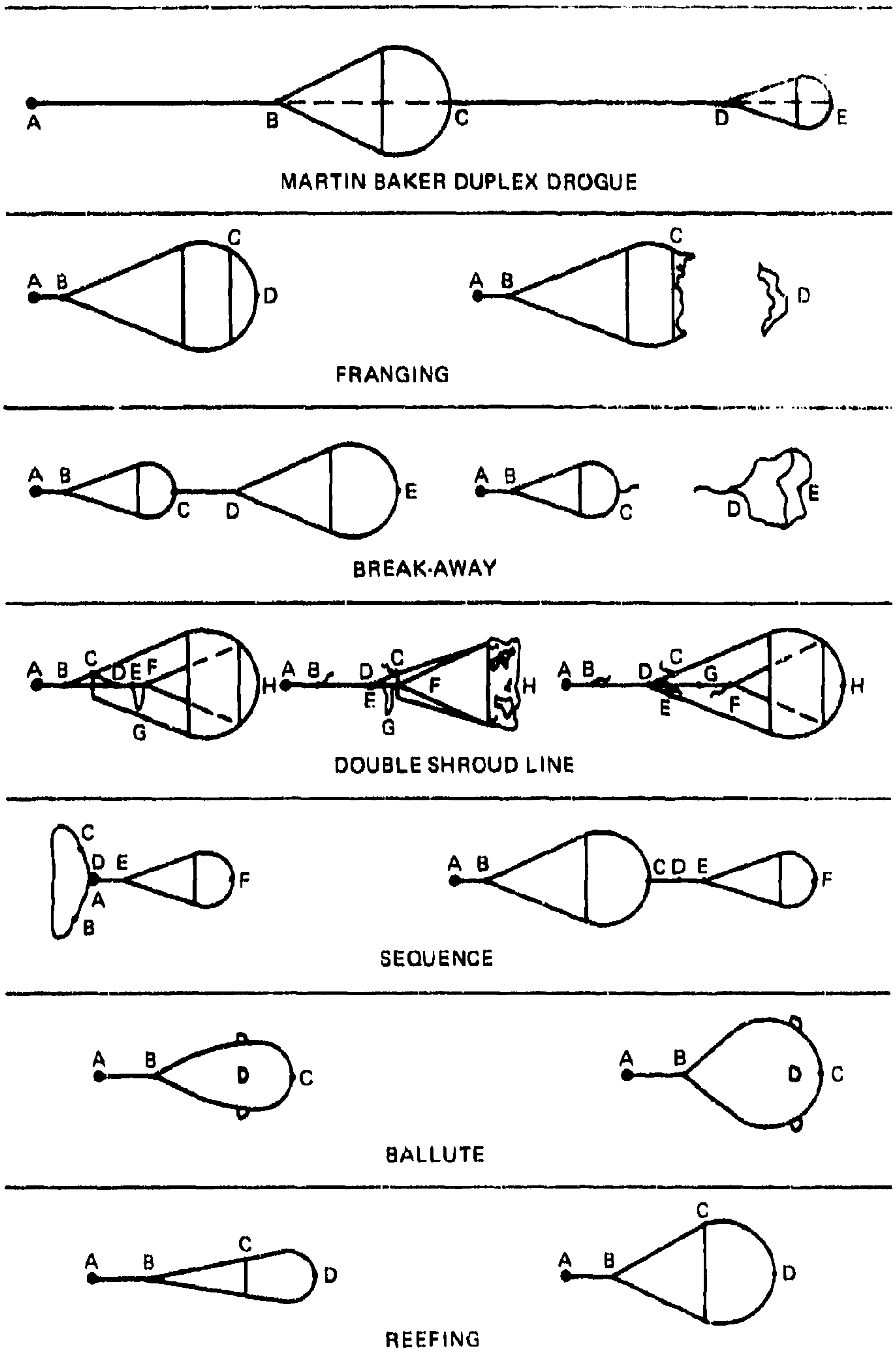


Figure 43 Drogue Chute Configurations

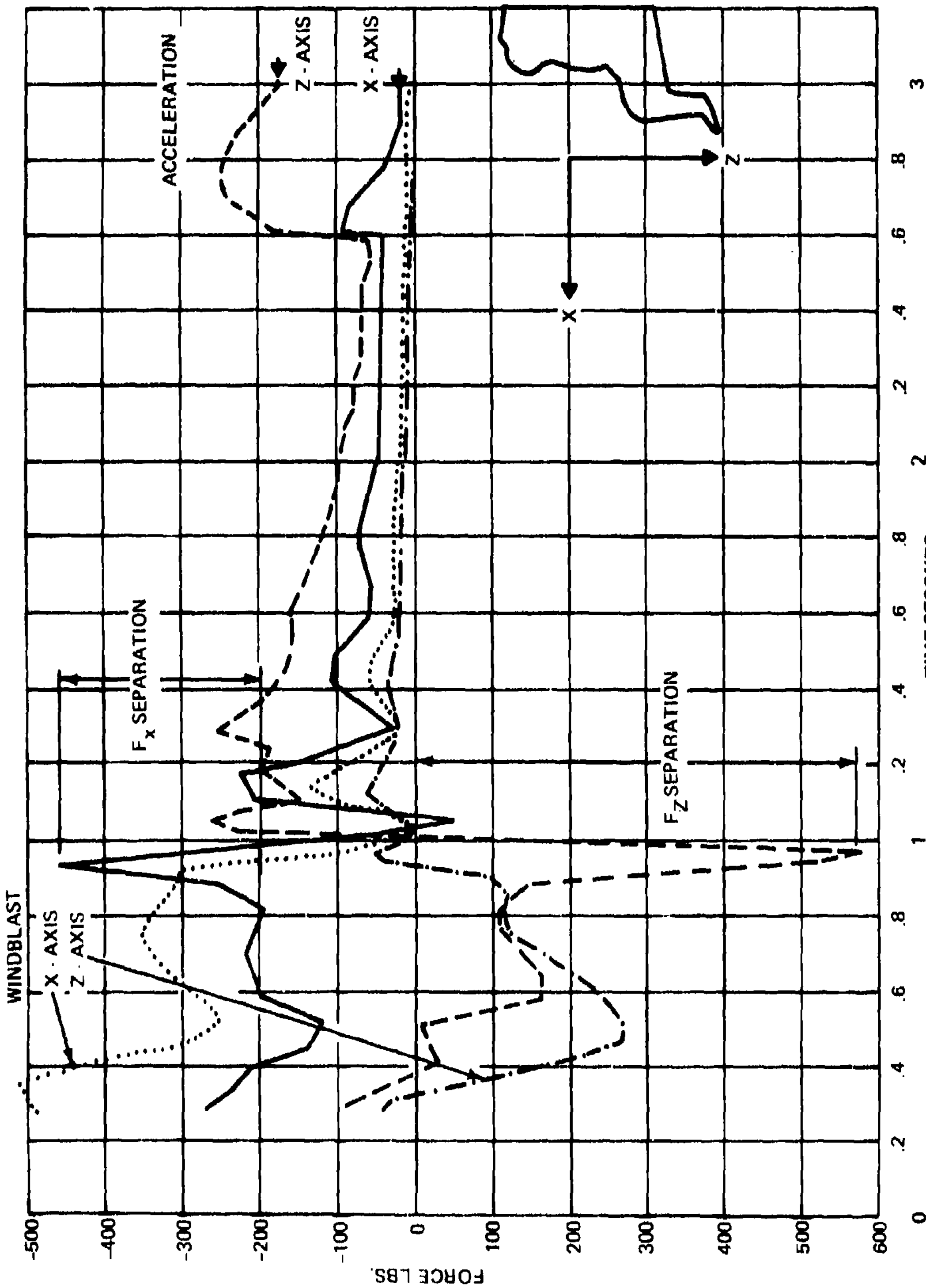


Figure 44 Head Forces/600 KTS. Sea Level Configuration 2

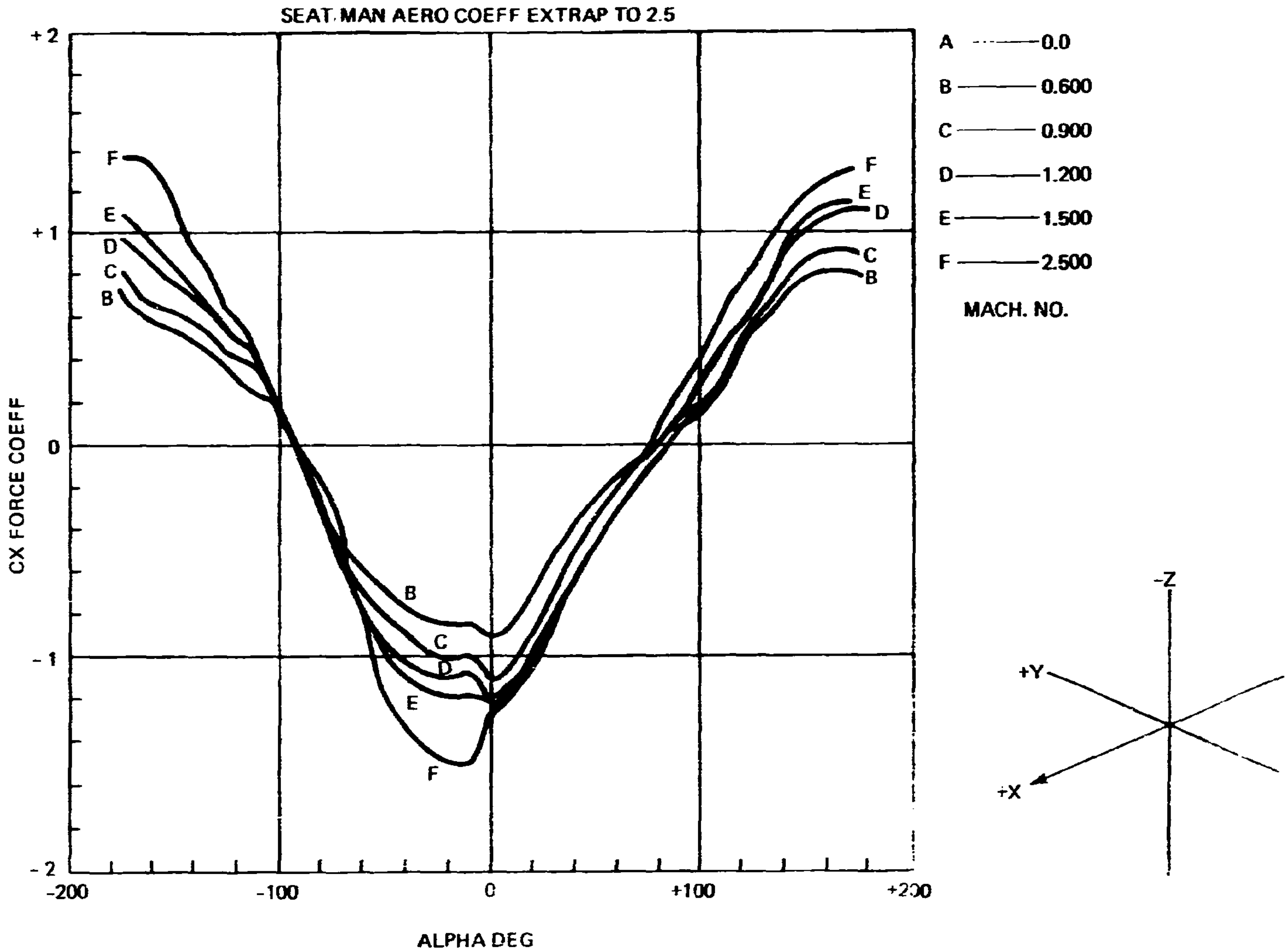


Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 1 of 6)

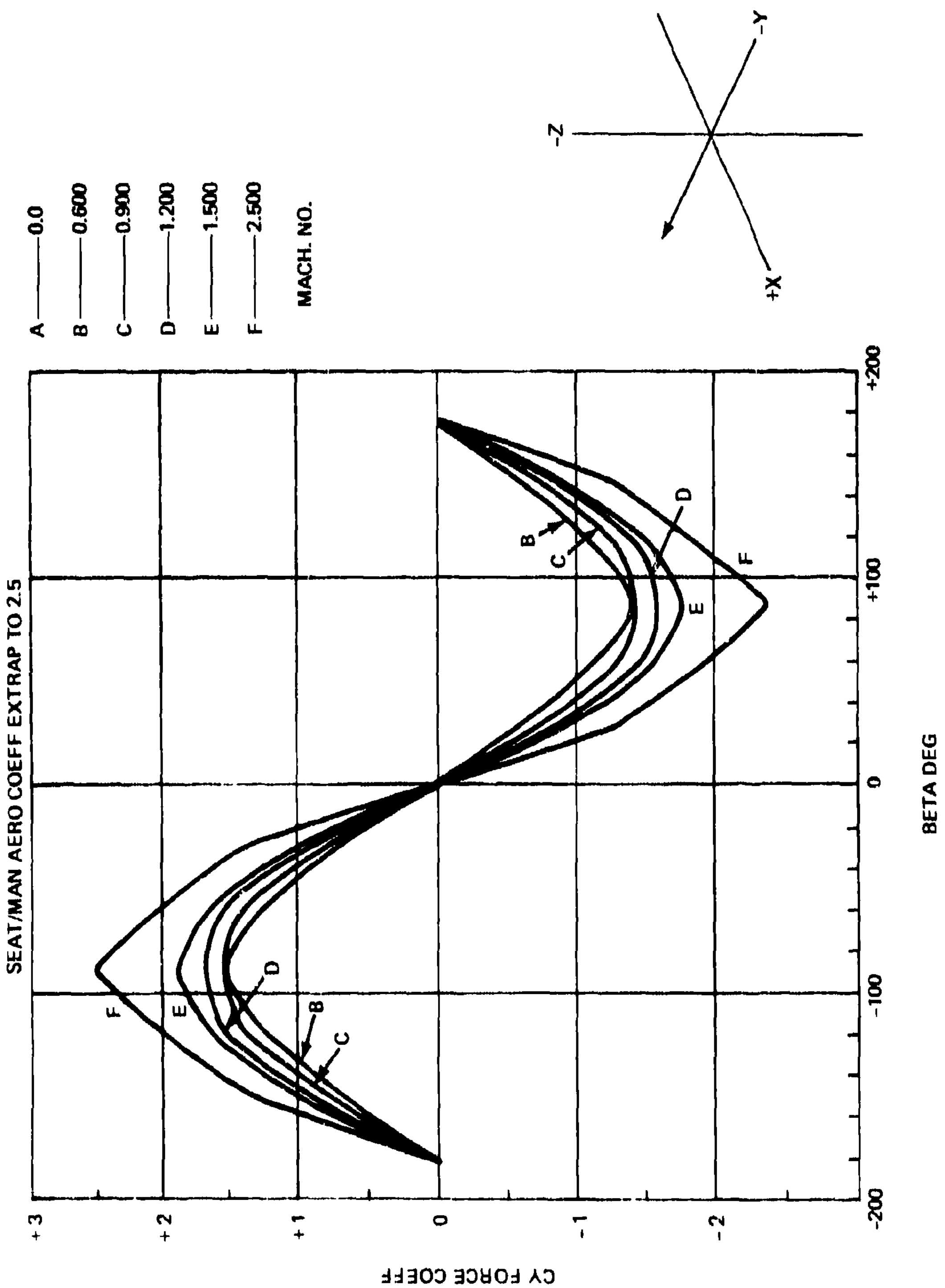


Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 2 of 6)

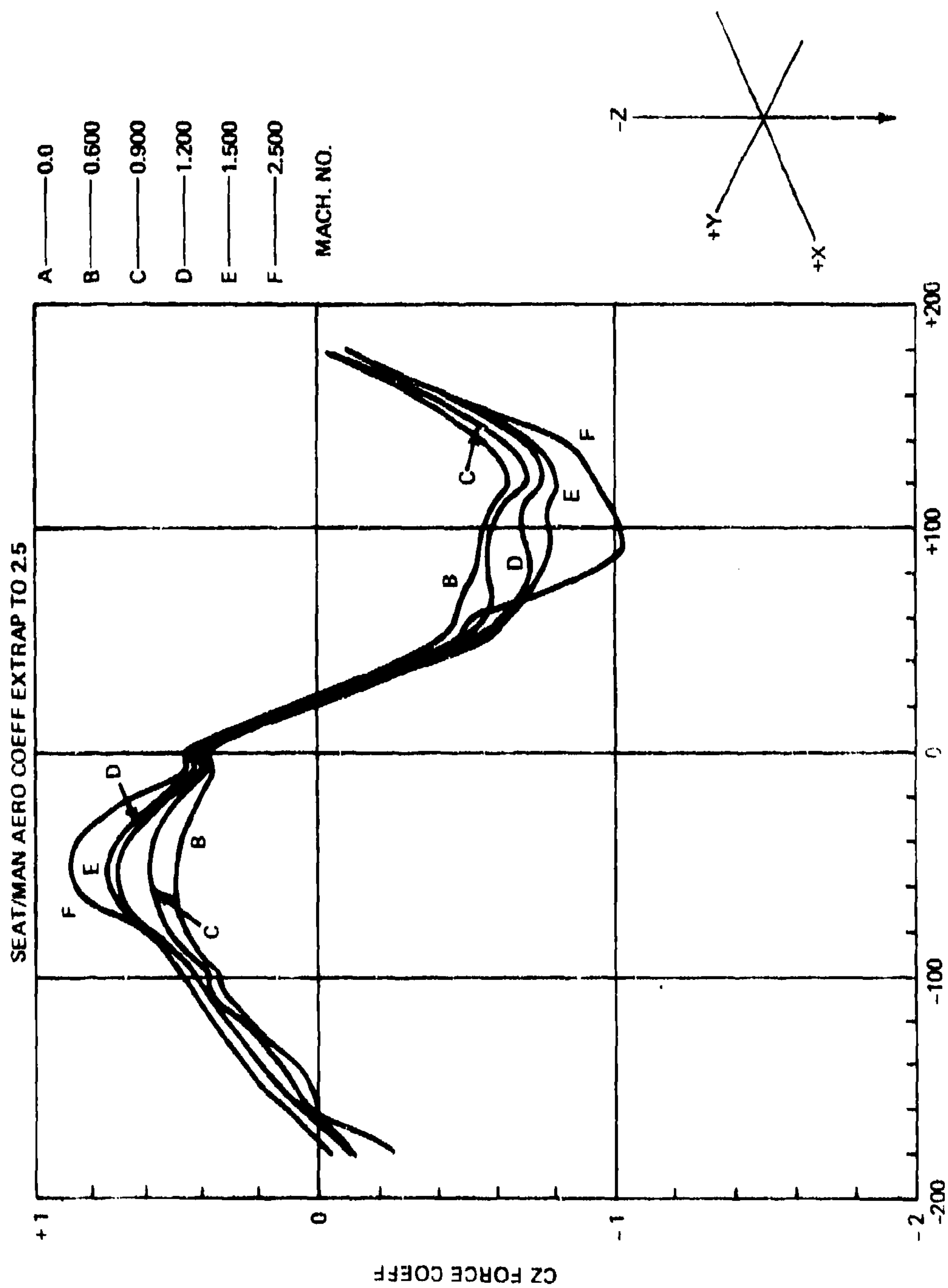
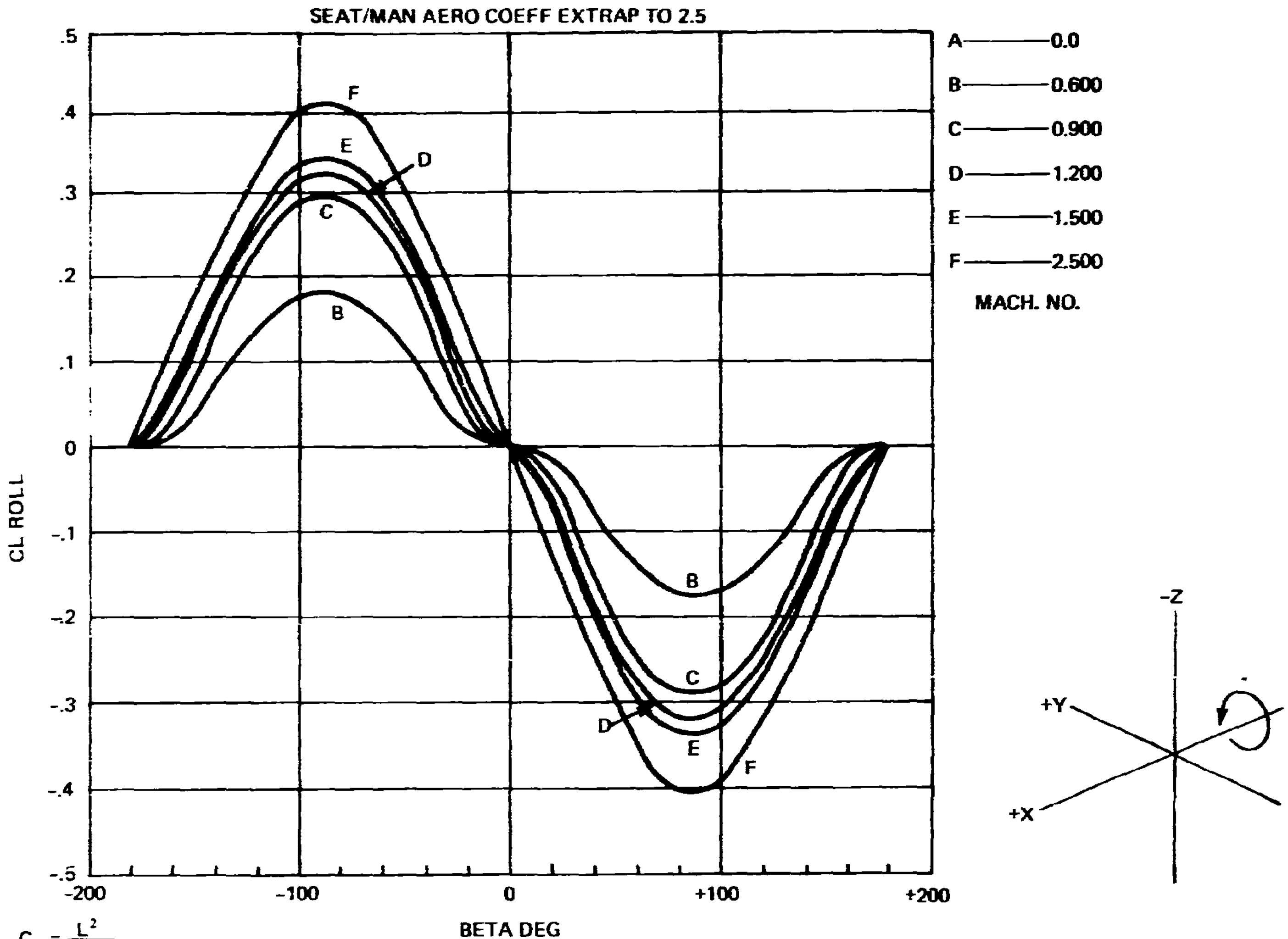


Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 3 of 5)



$C_L = \frac{L^2}{q\,SL^i}$

L^2 = ROLLING MOMENT

Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 4 of 6)

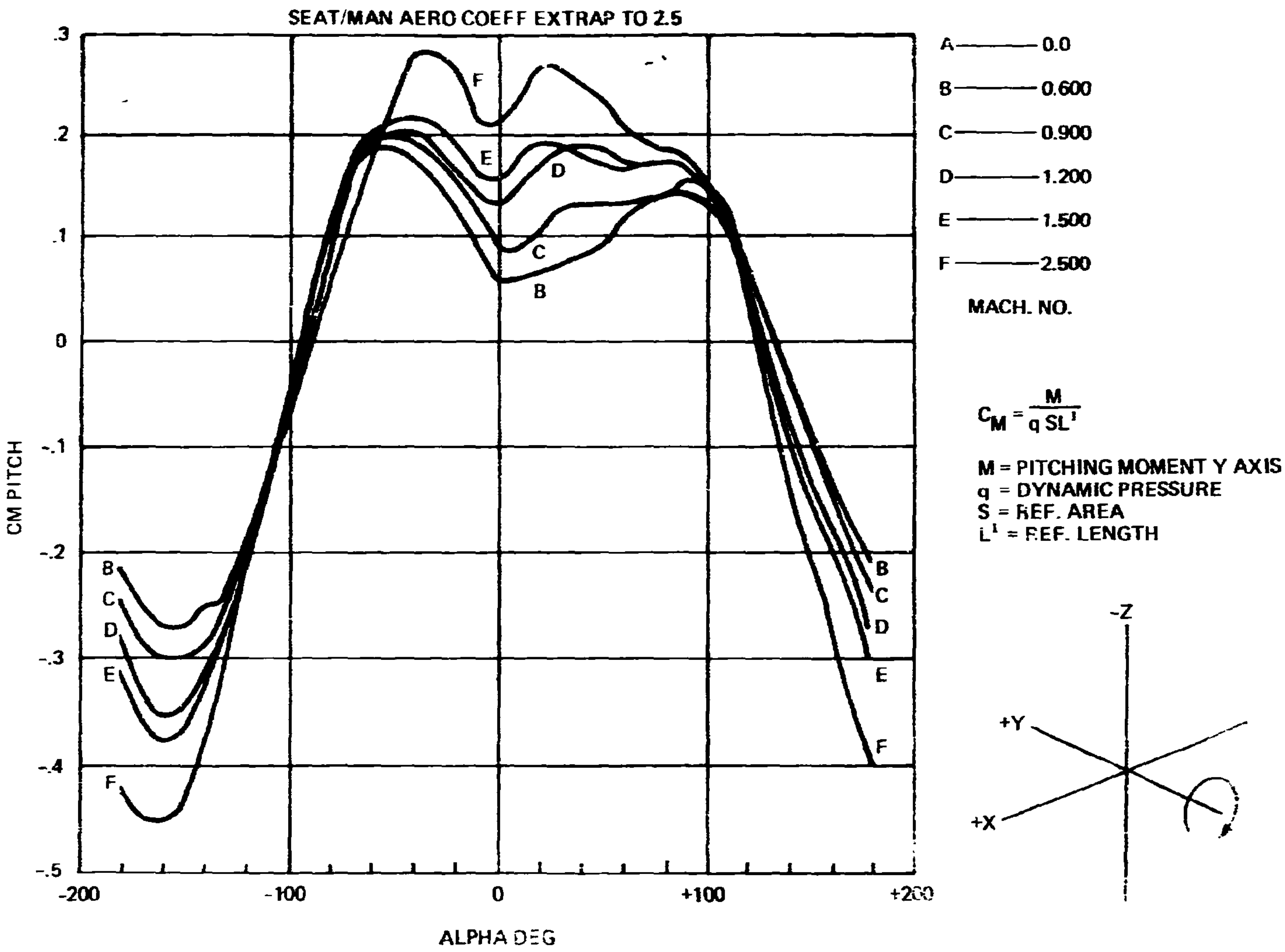
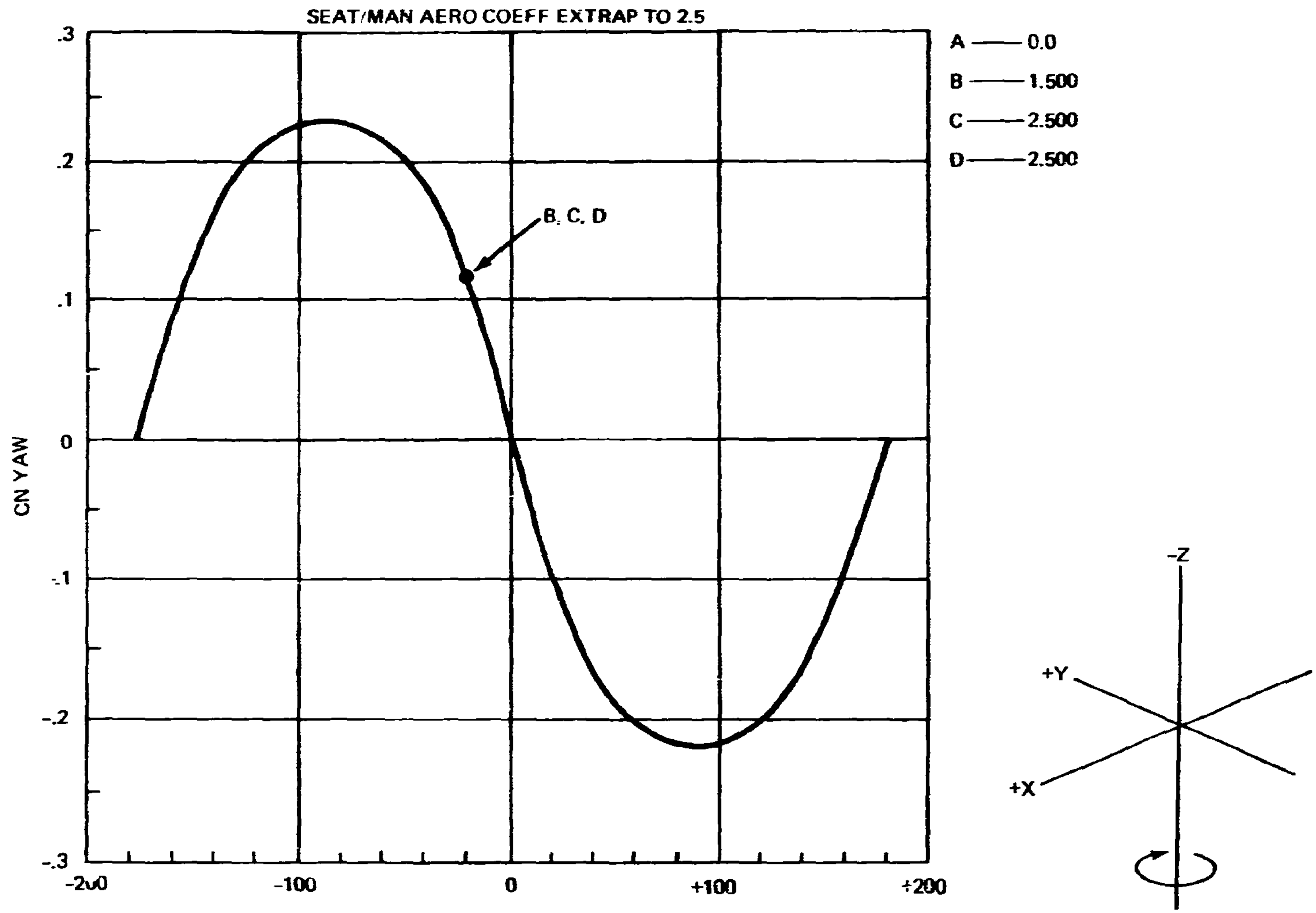


Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 5 of 6



$C_N = \frac{N}{q\,SL'}$
N = YAWING MOMENT

Figure 45 Aerodynamic Data (Seat/Man Aero Coeff) (Sheet 6 of 6)

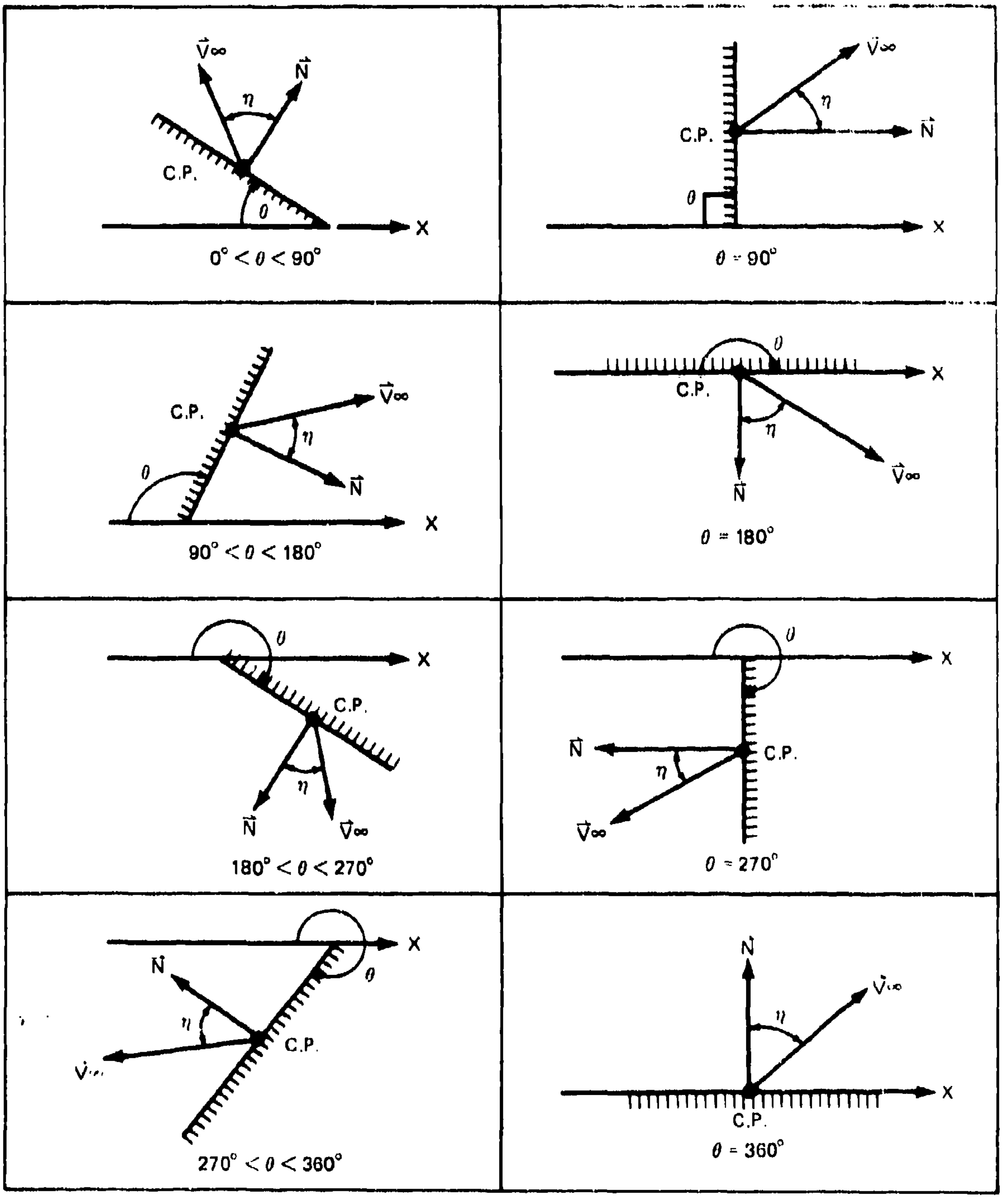


Figure 46 Normal Vector Convention

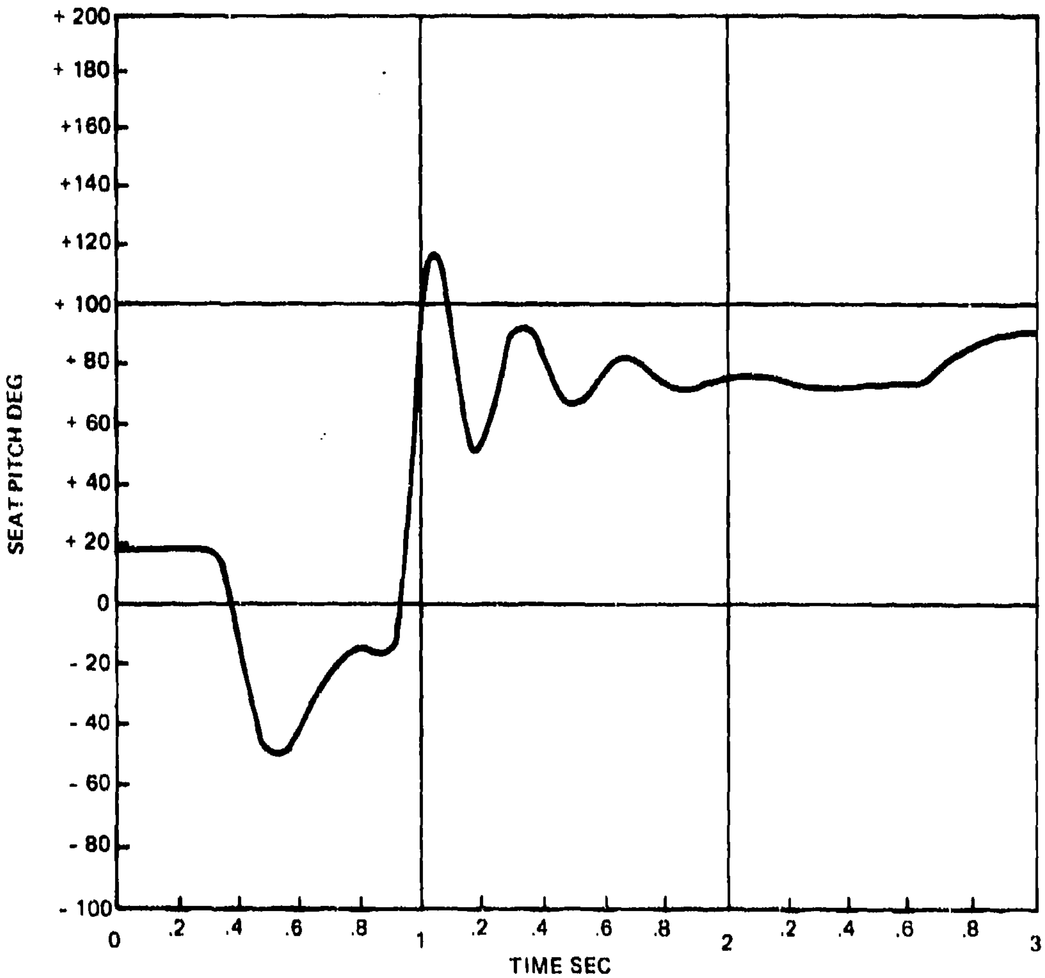


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 1 of 9)

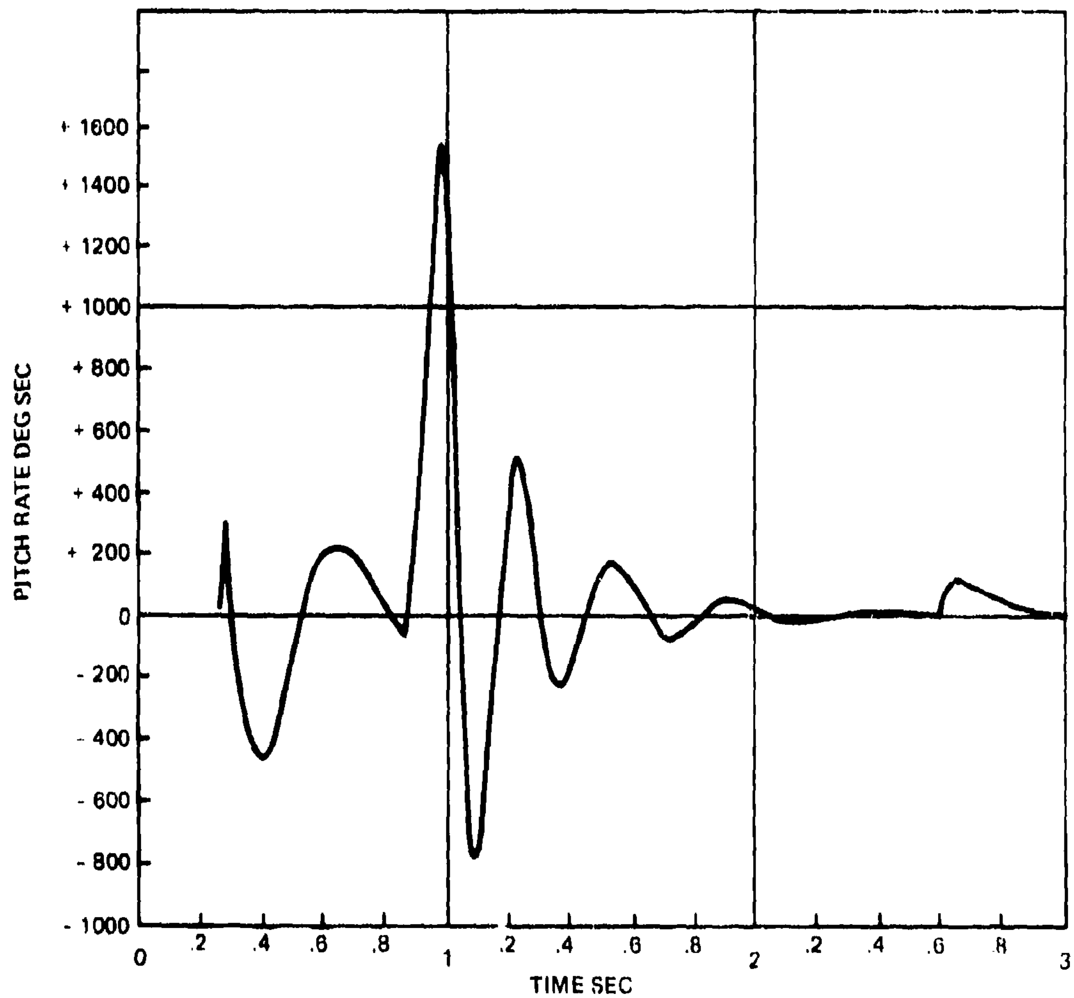


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 2 of 9)

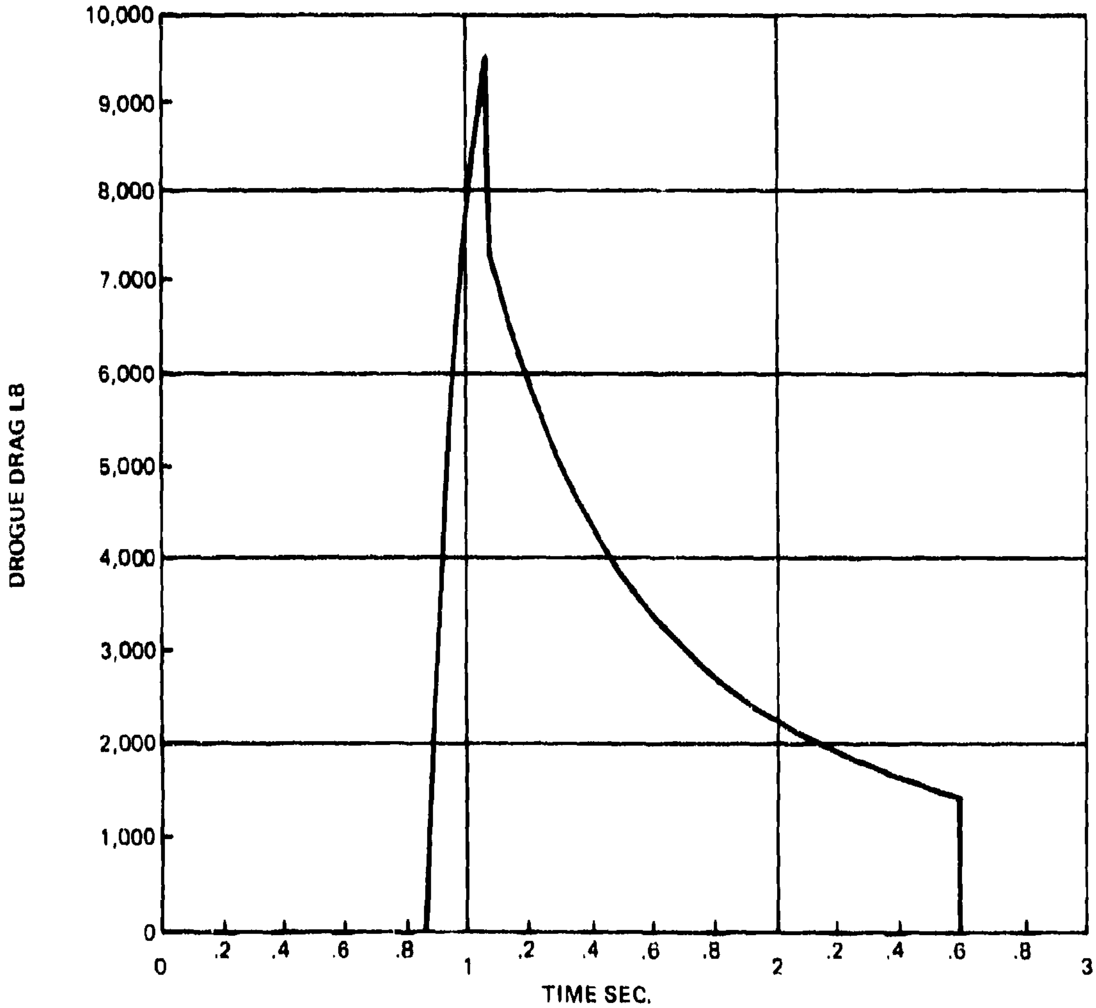


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 3 of 9)

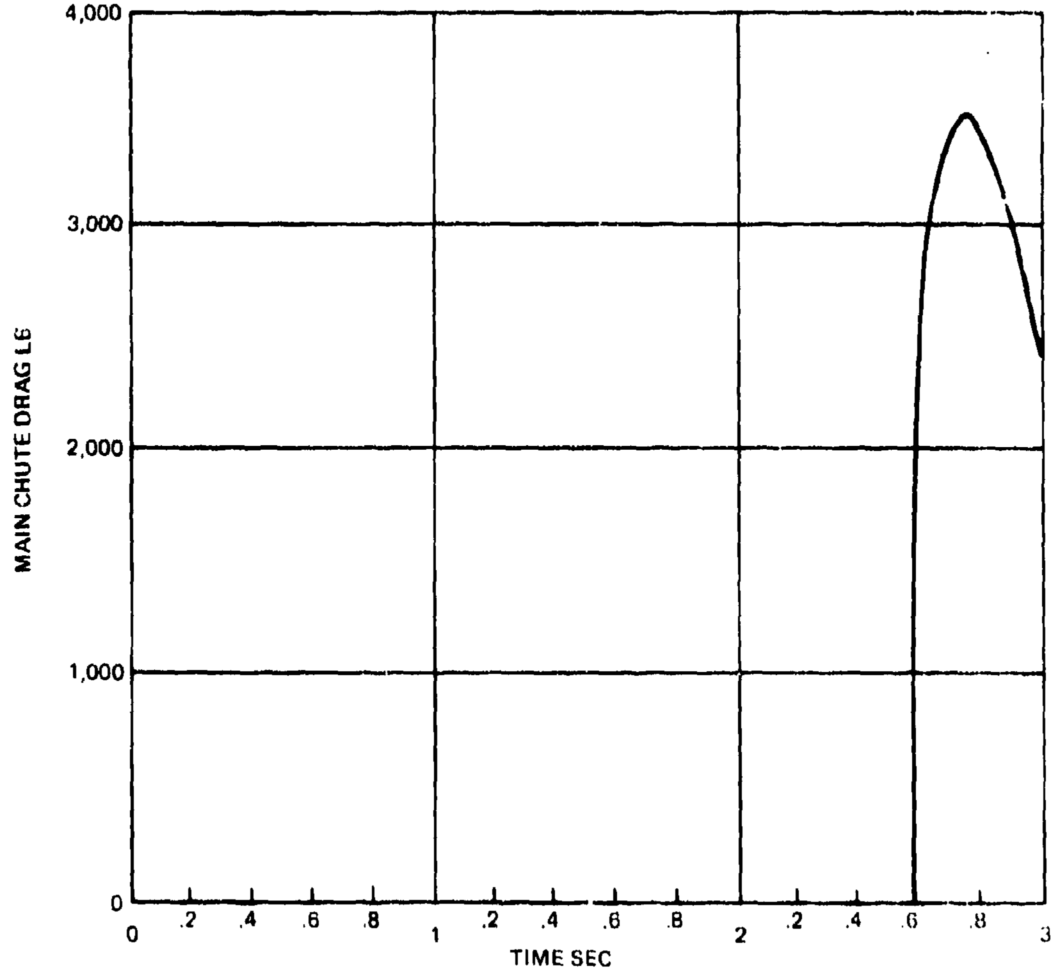


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 4 of 9)

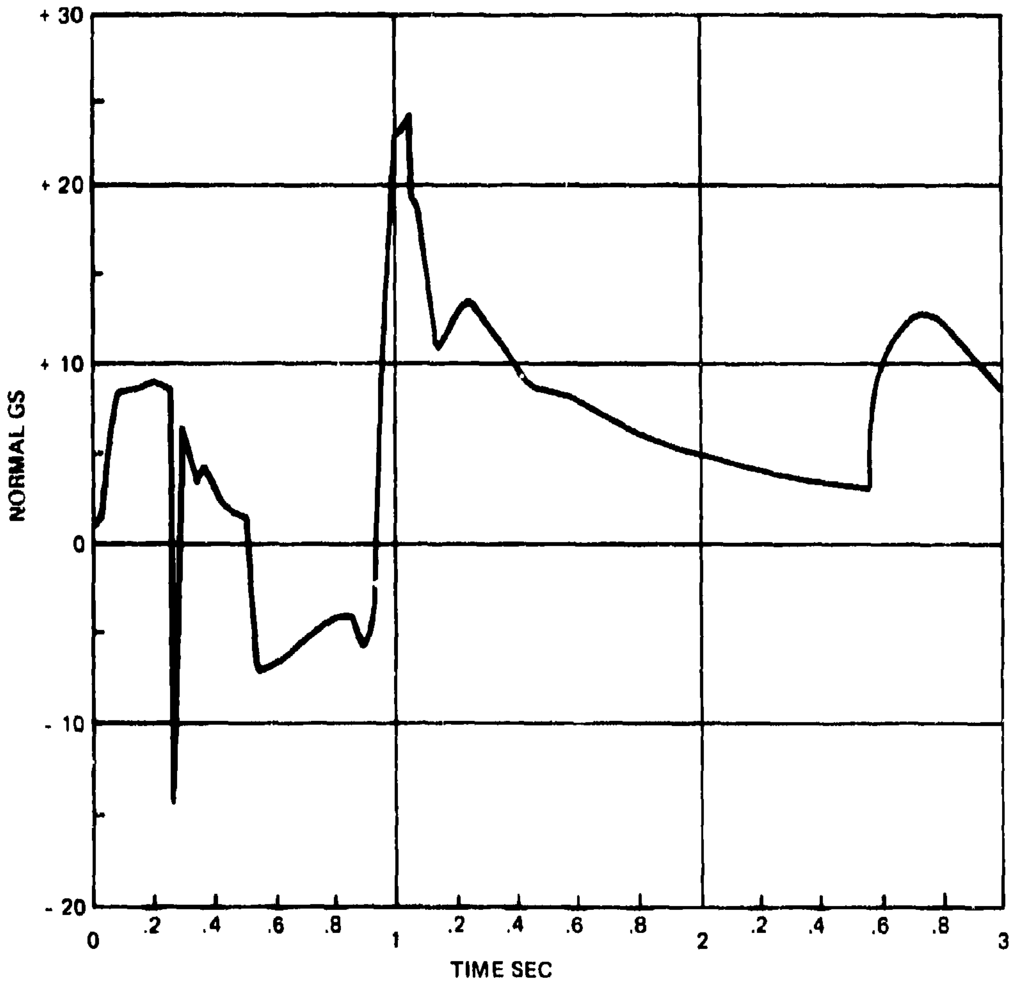


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 5 of 9)

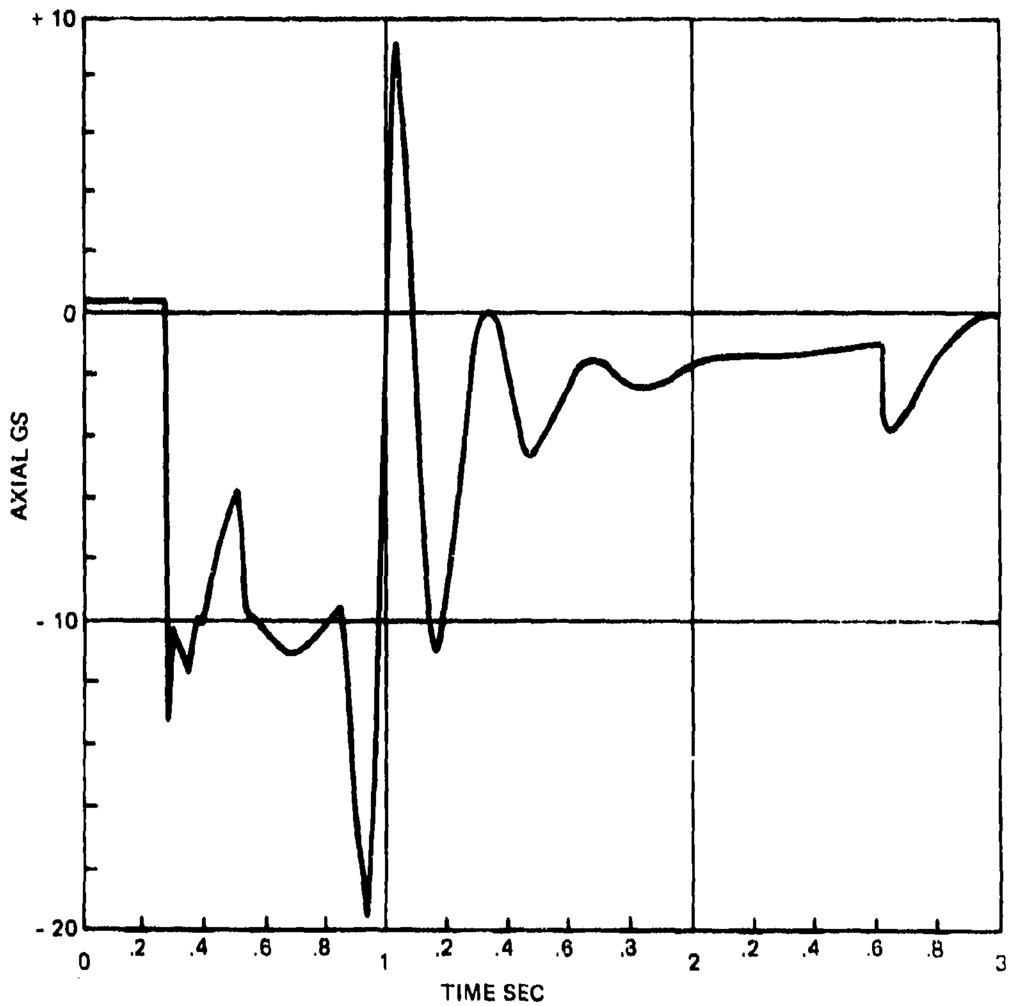


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 6 of 9)

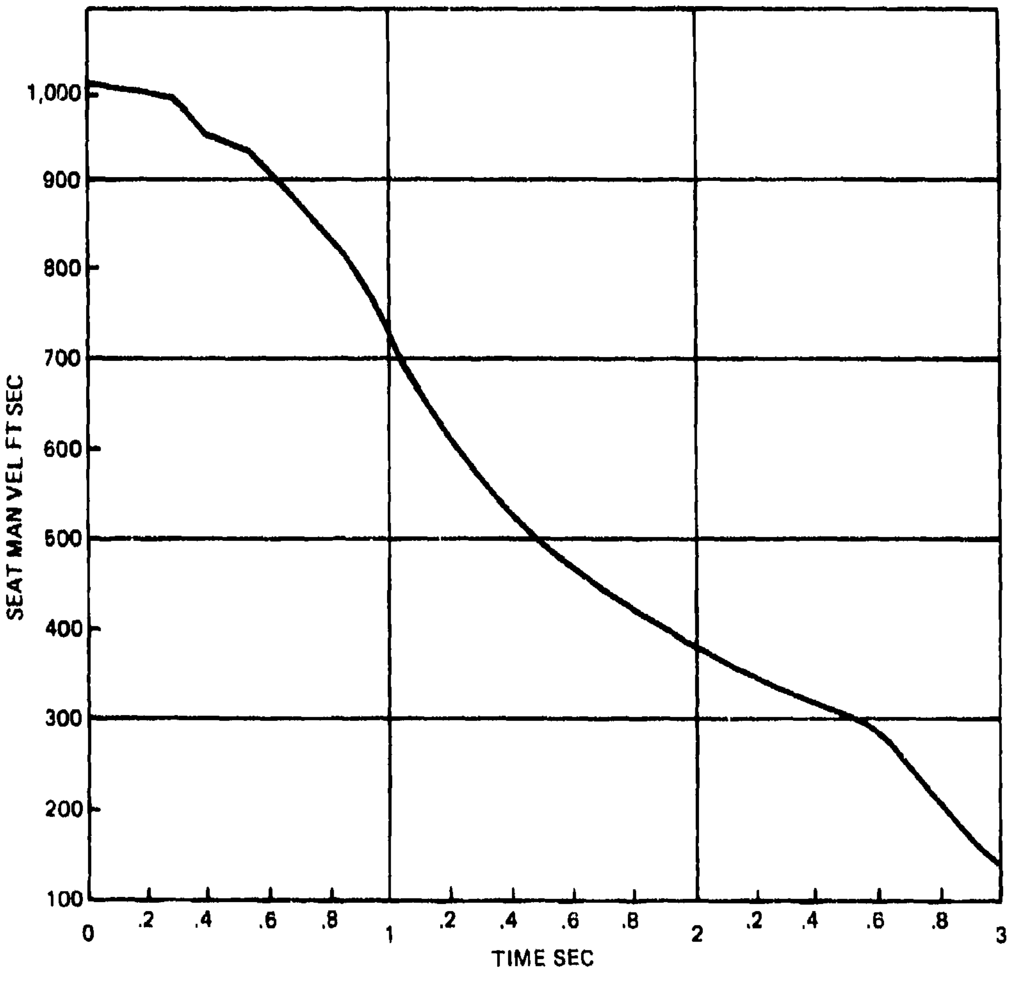


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 7 of 9)

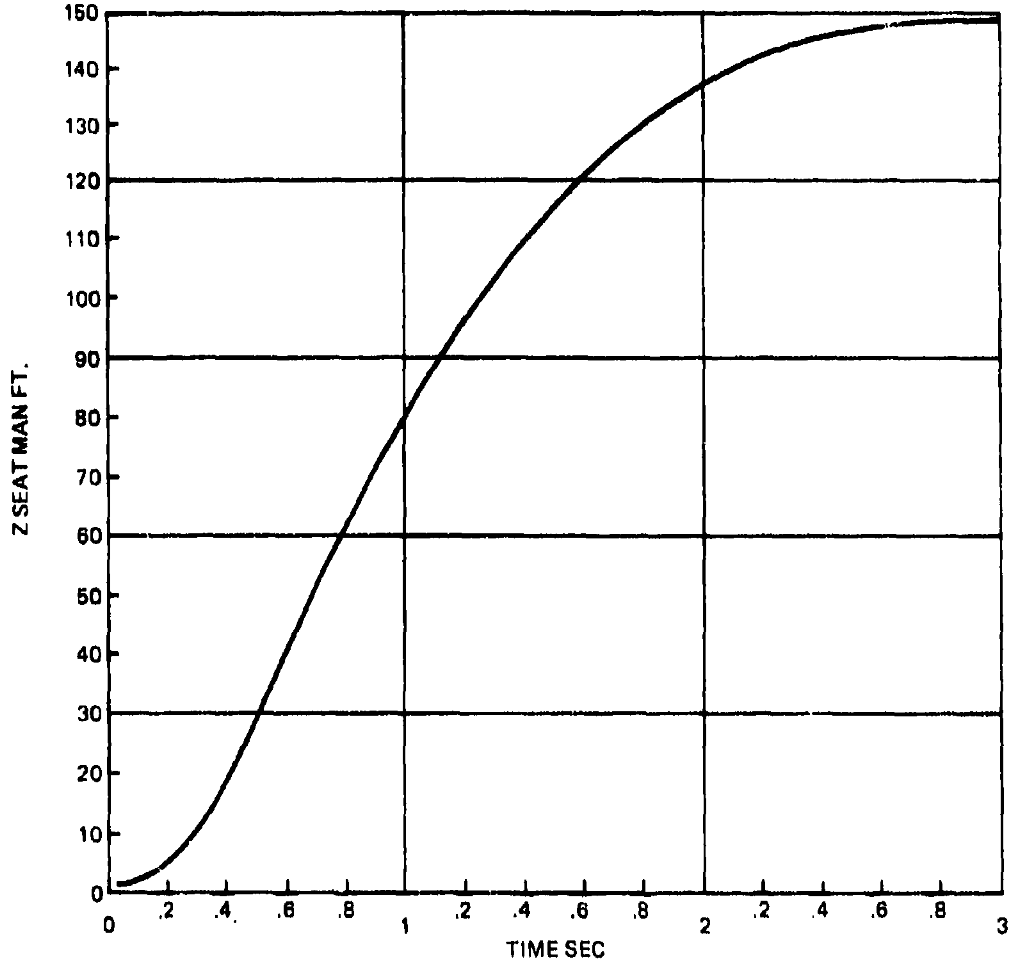


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 8 of 9).

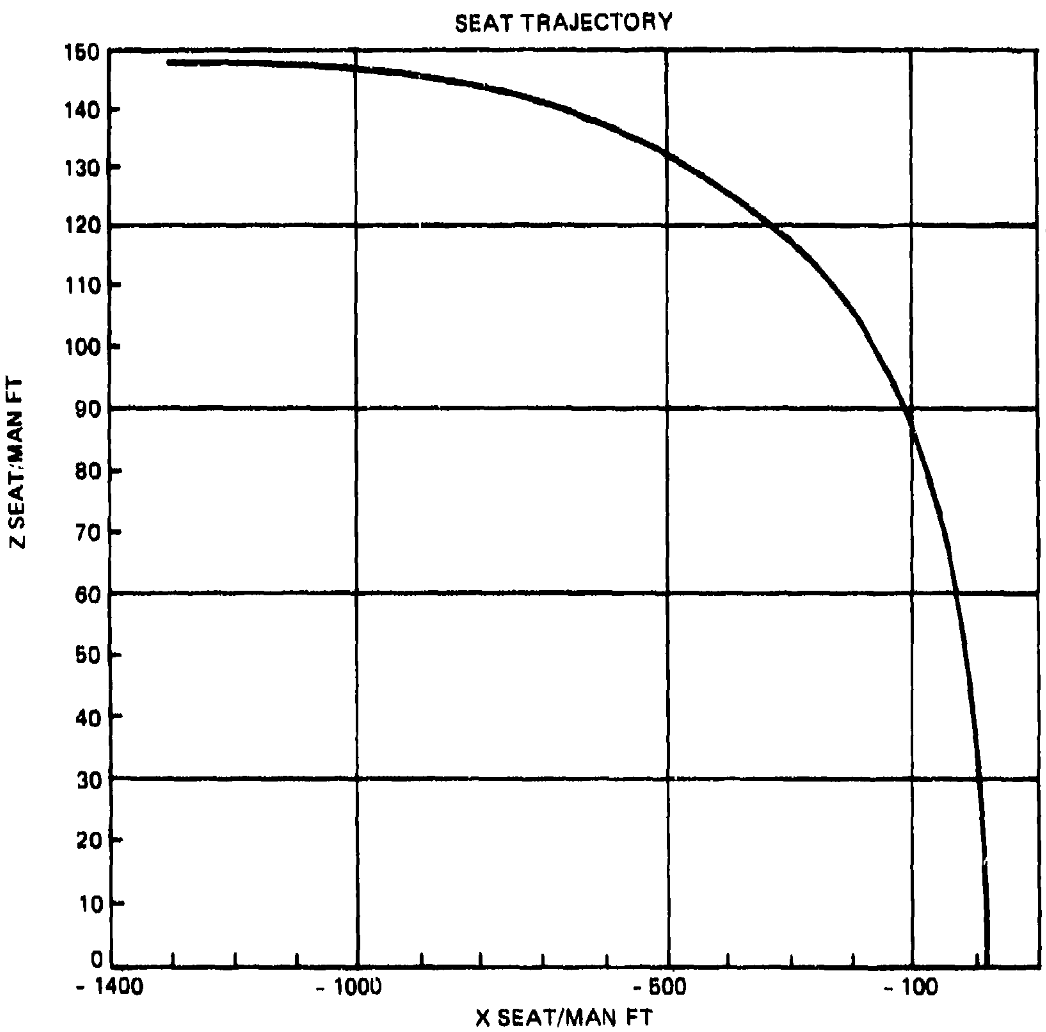


Figure 47 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat (Sheet 9 of 9)

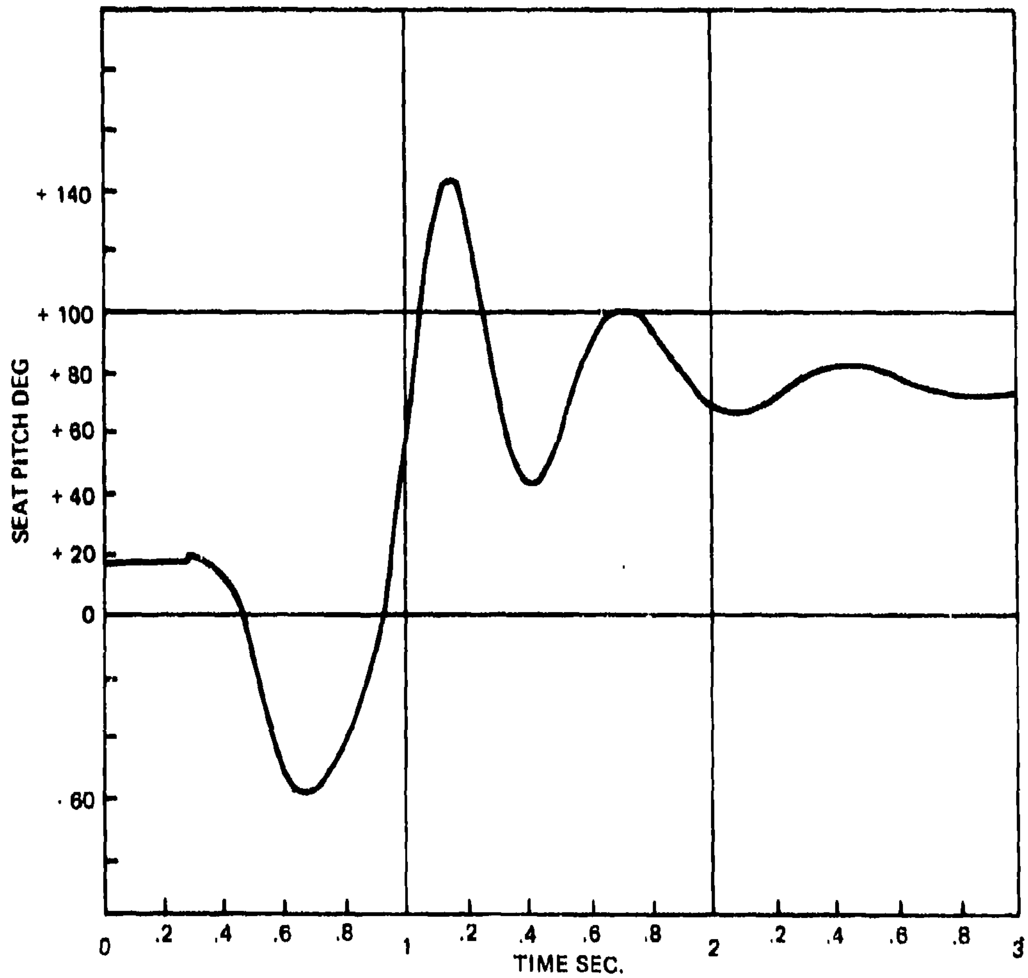


Figure 48 Computer Run — 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 1 of 6)

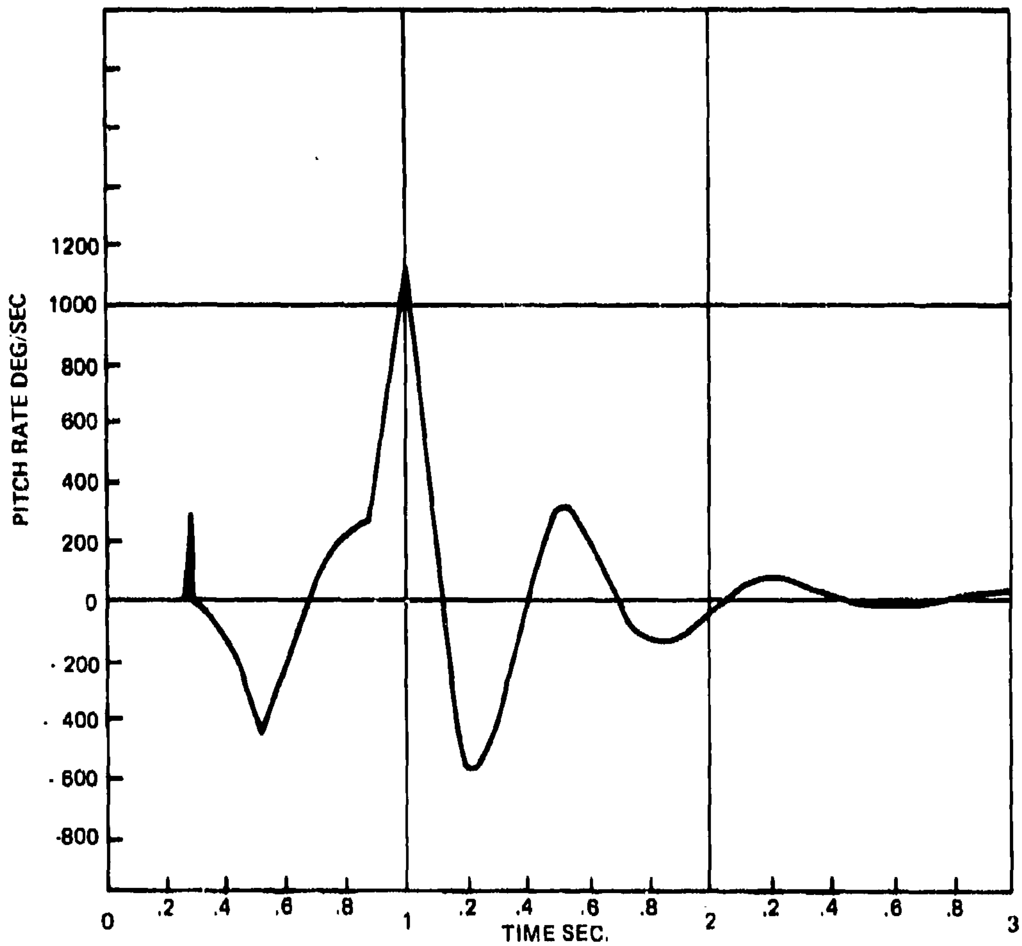


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 2 of 8)

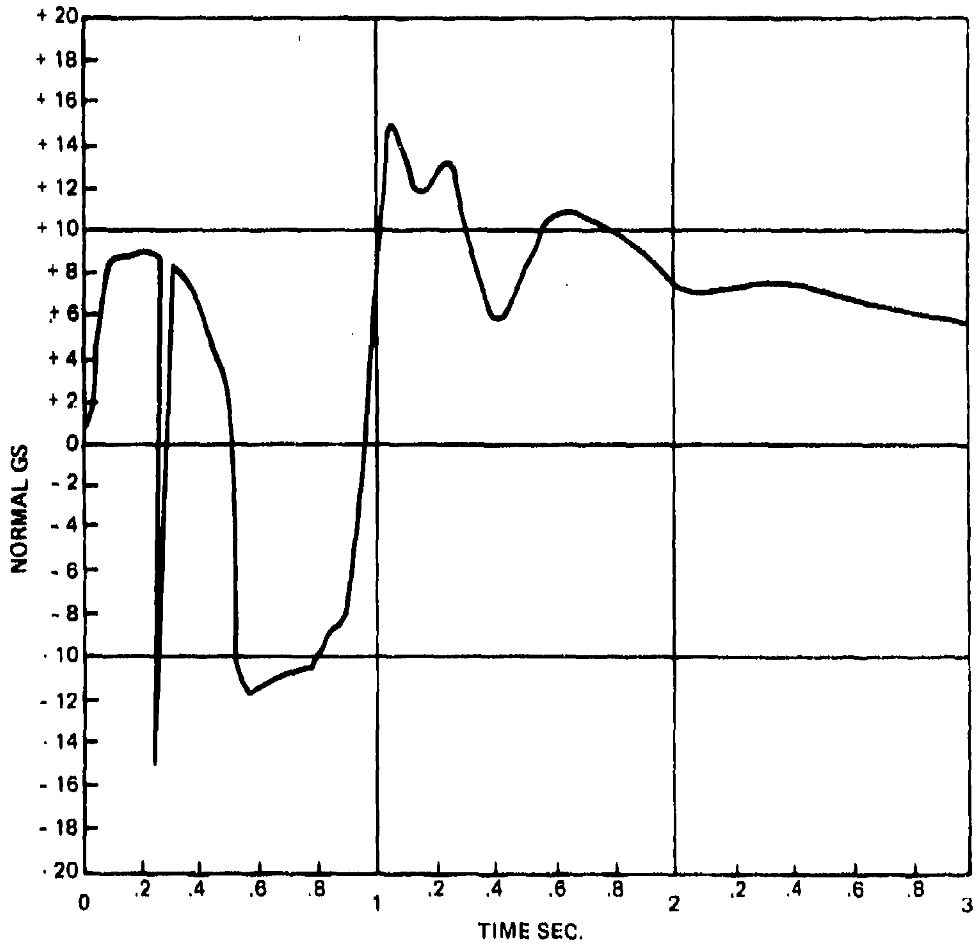


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 3 of 8)

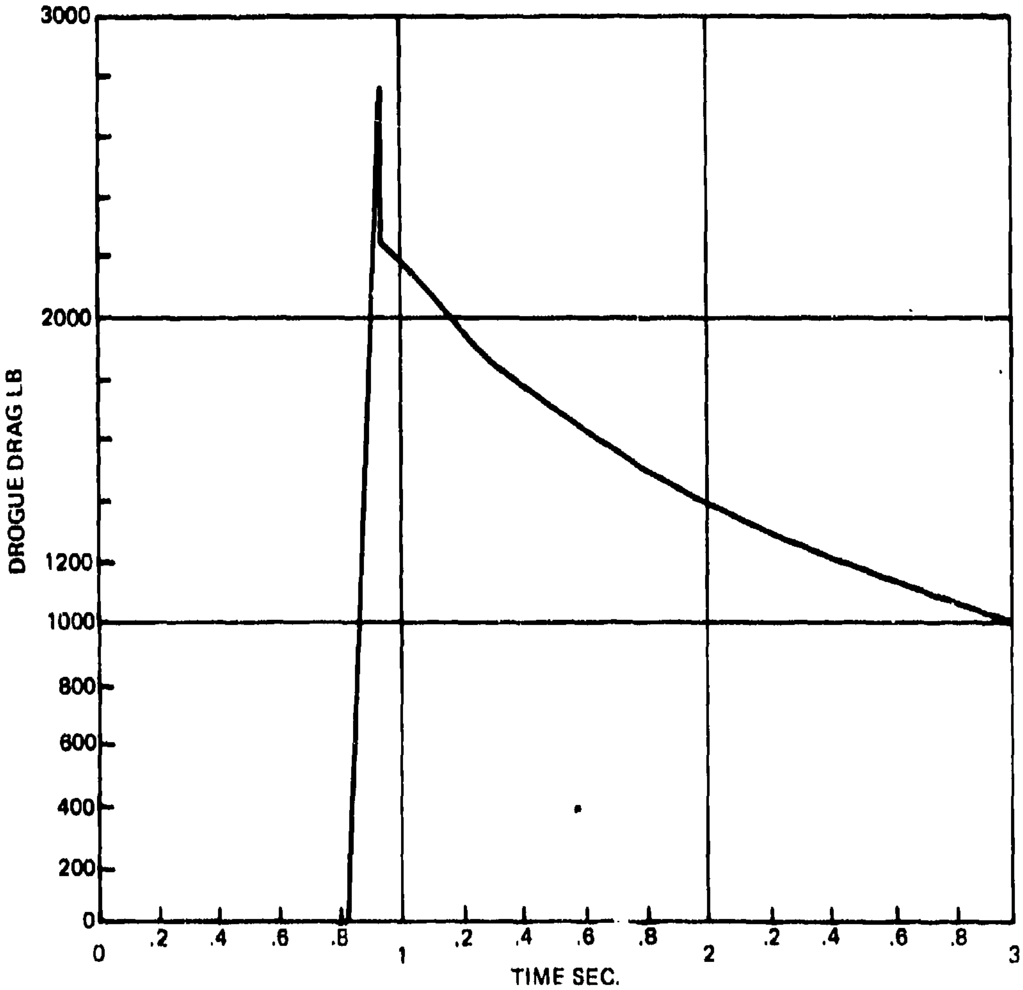


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 4 of 8)

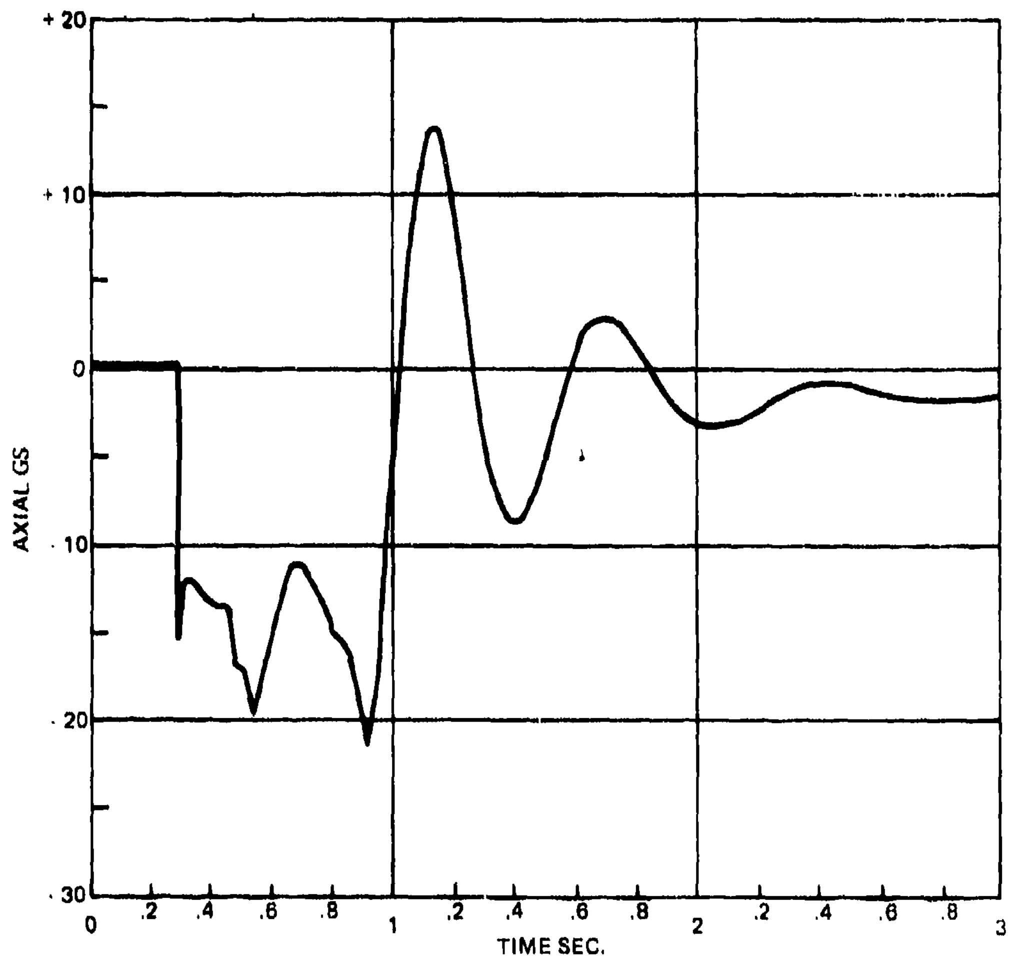


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 5 of 8)

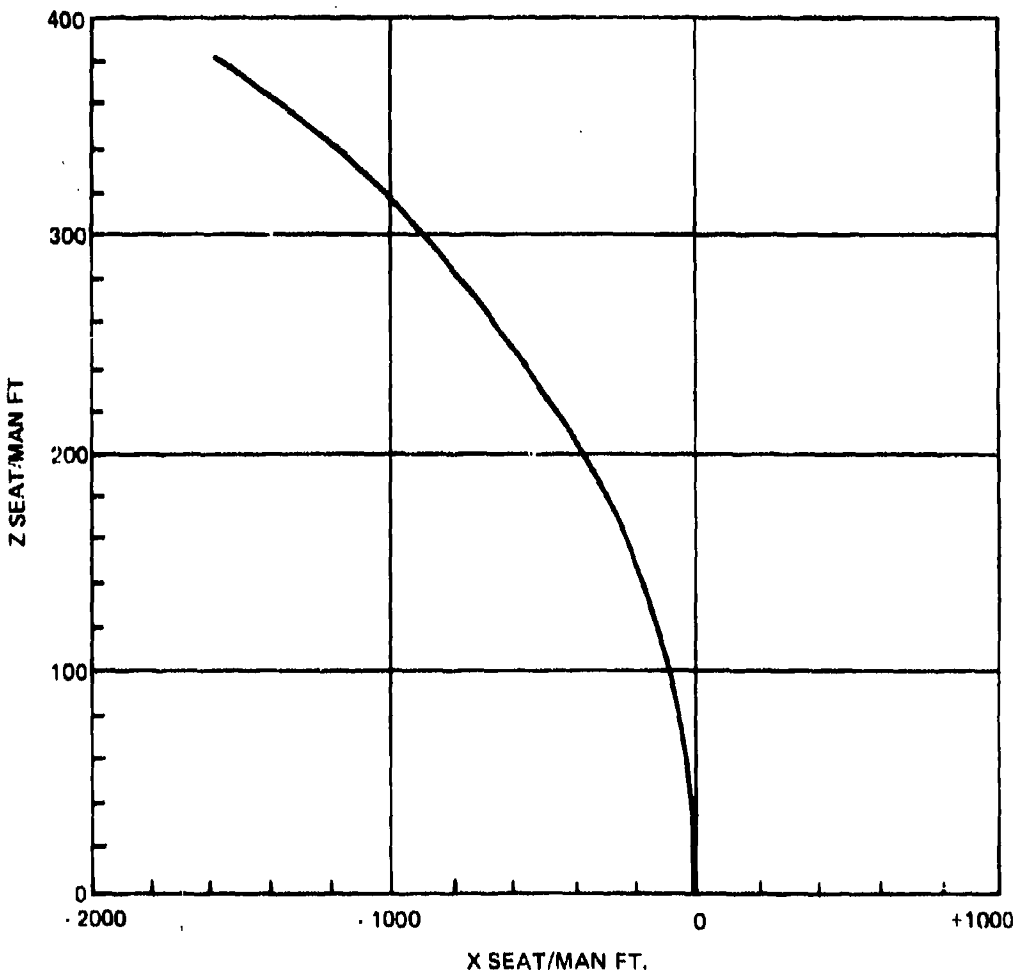


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 6 of 8)

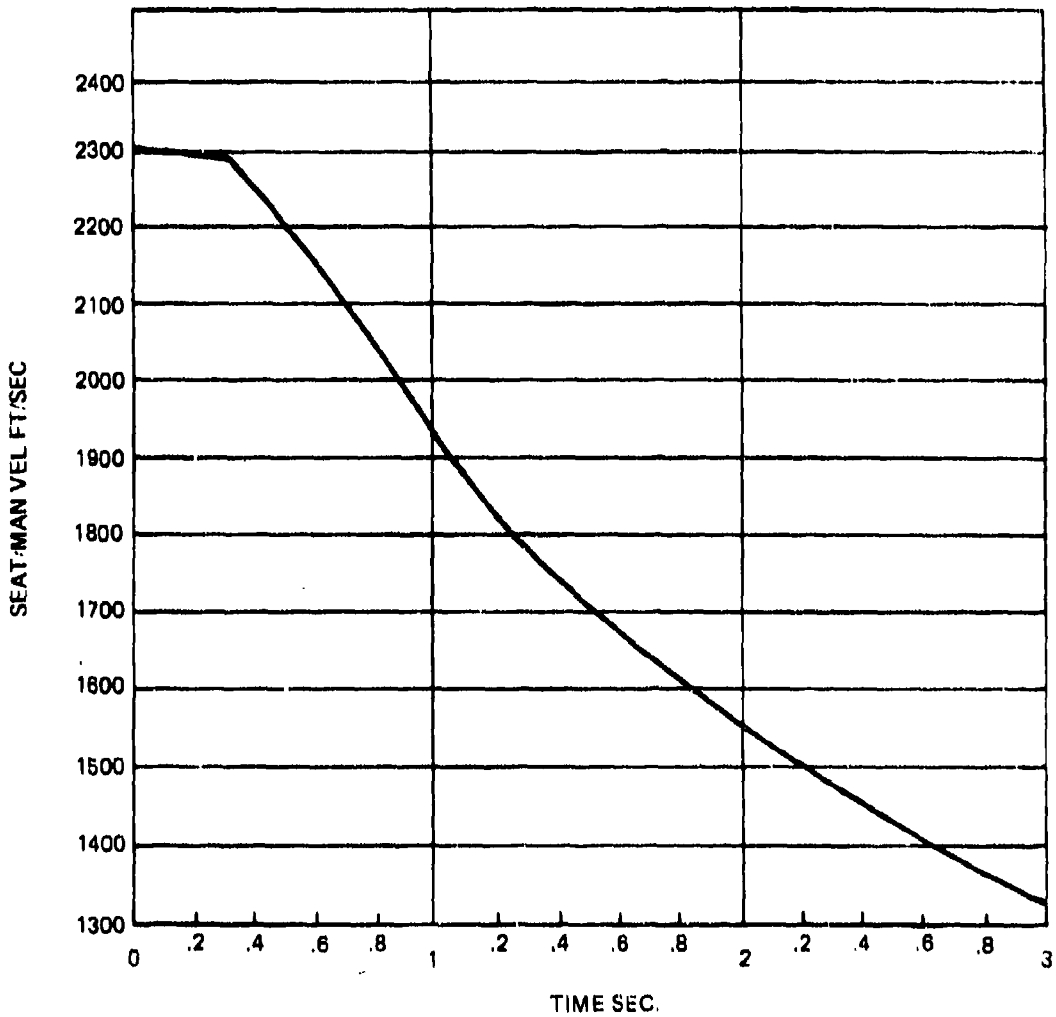


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 7 of 8)

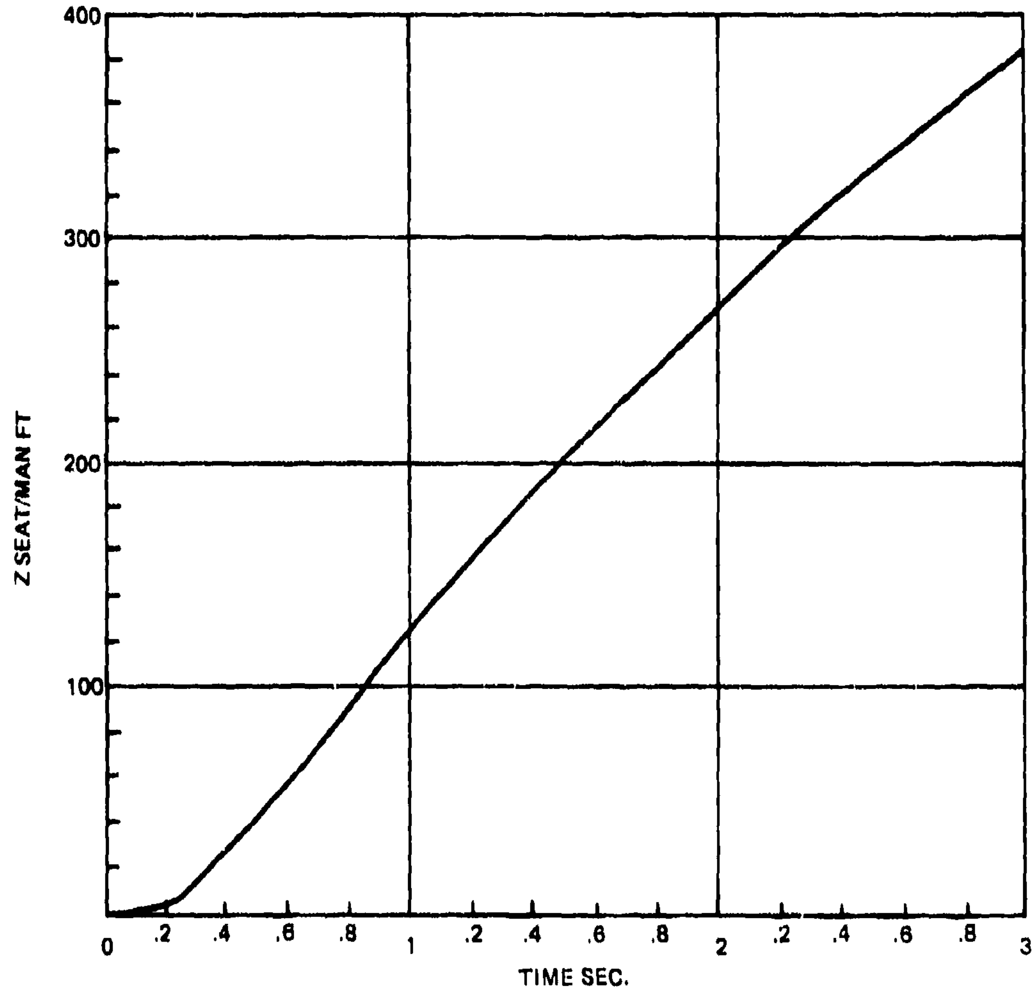


Figure 48 Computer Run – 1365 KTS 45K Ft. MK-GRU7 Type Seat (Sheet 8 of 8)

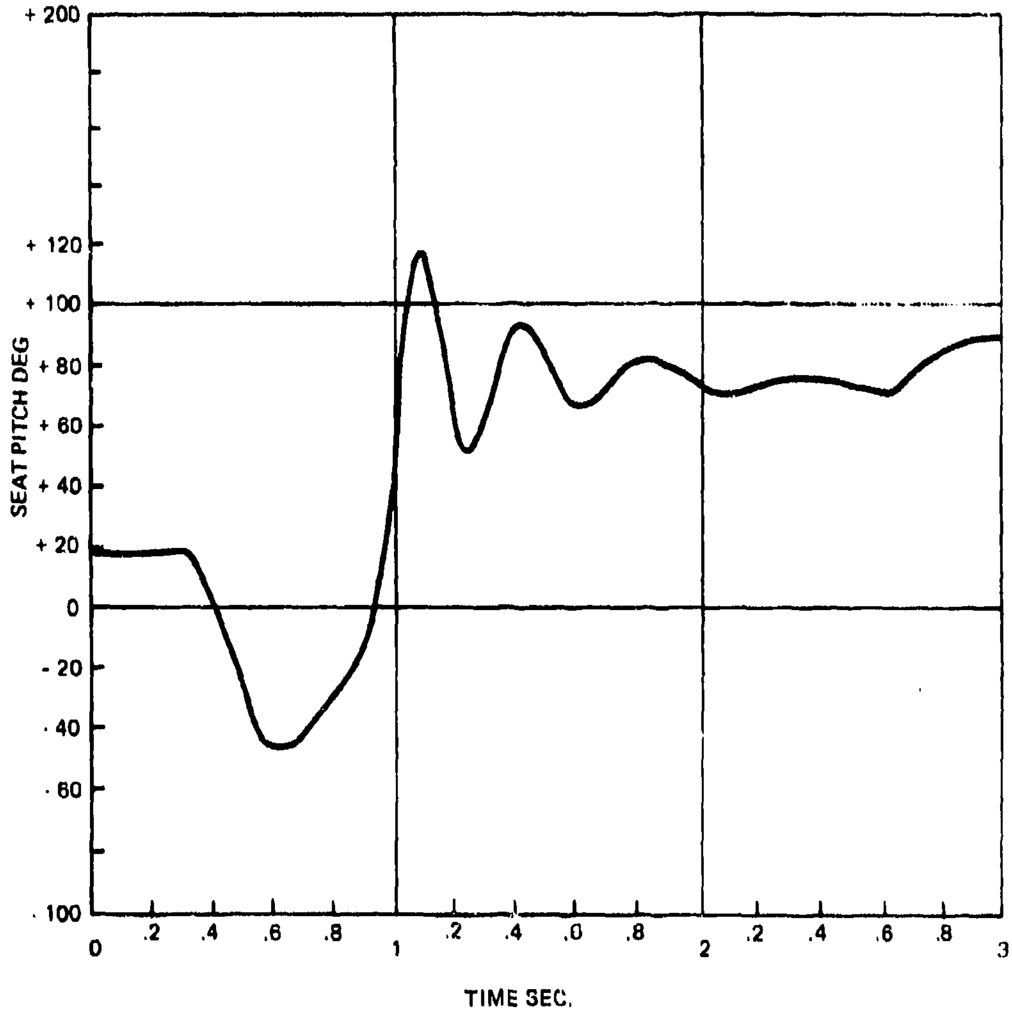


Figure 49 Computer Run - 436 KTS. S. L. MK-GRU7 Type Seat (Sheet 1 of 9)

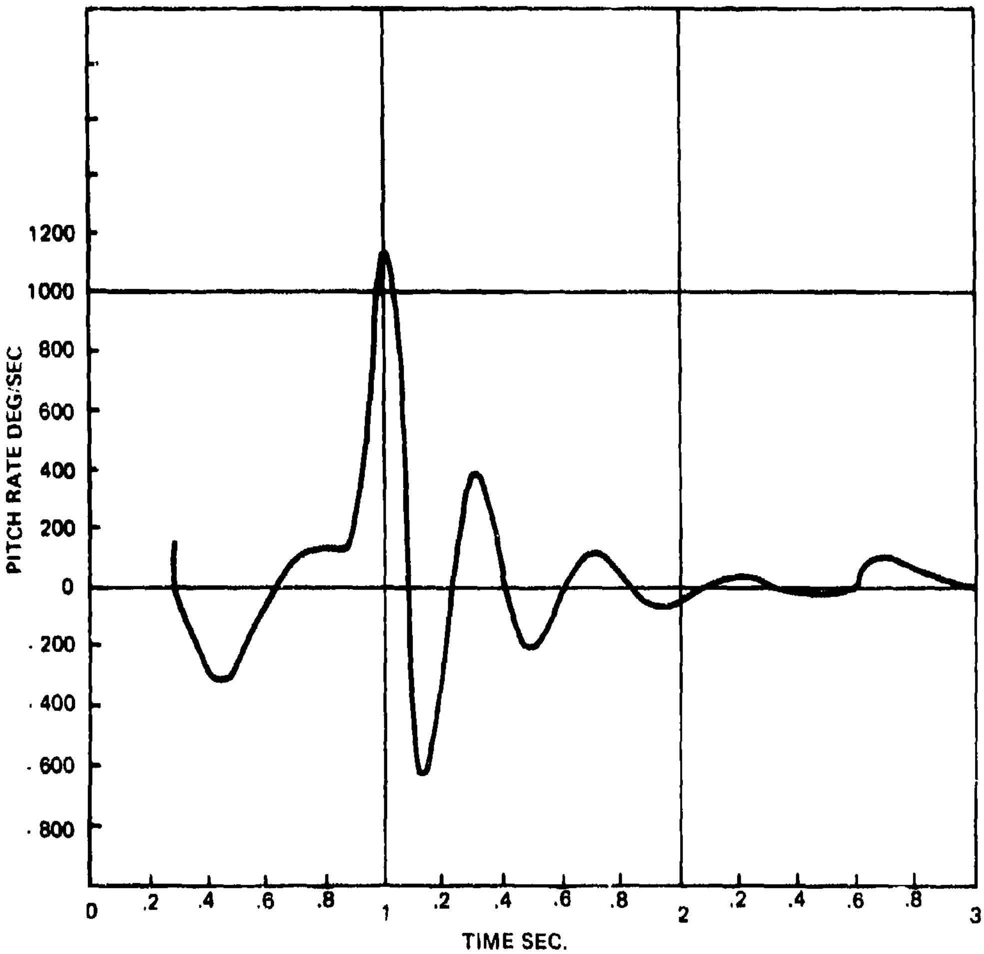


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 2 of 9)

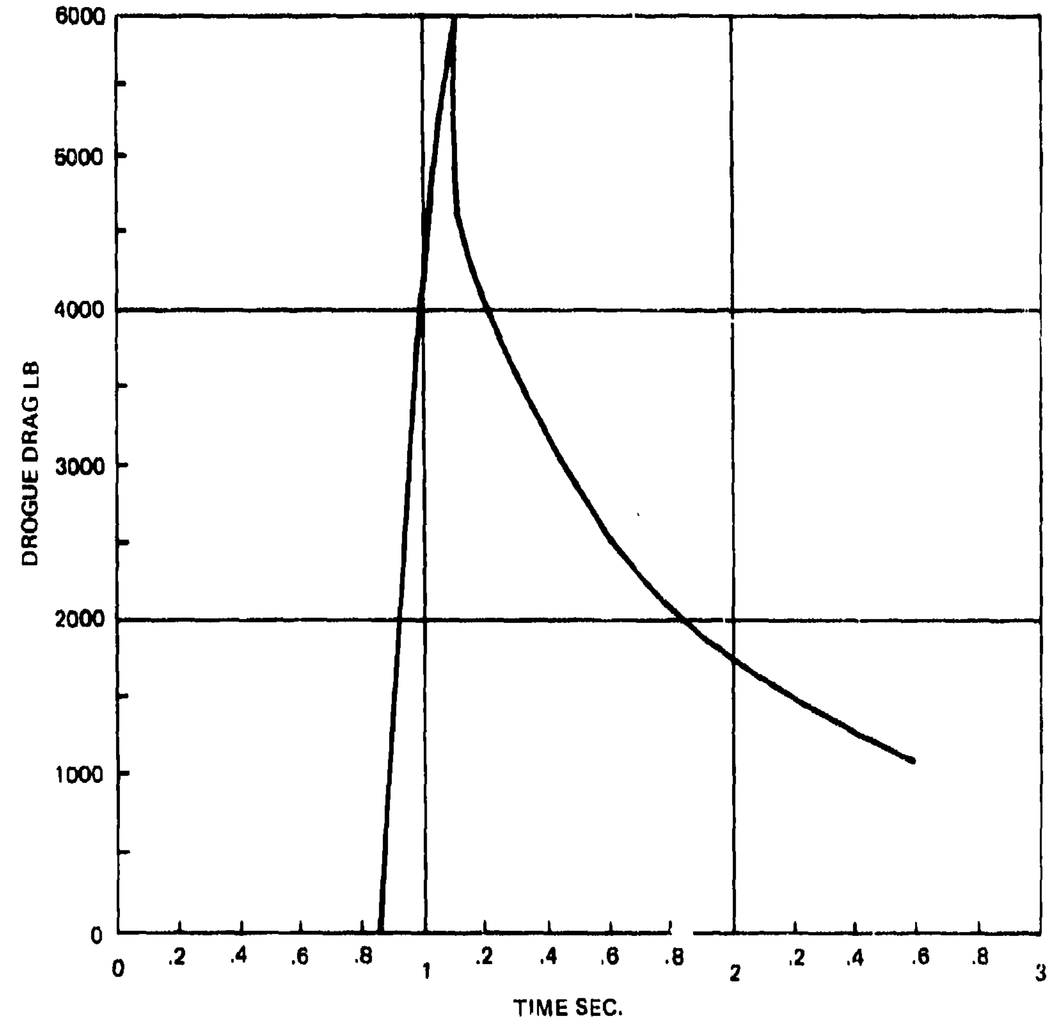


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 3 of 9)

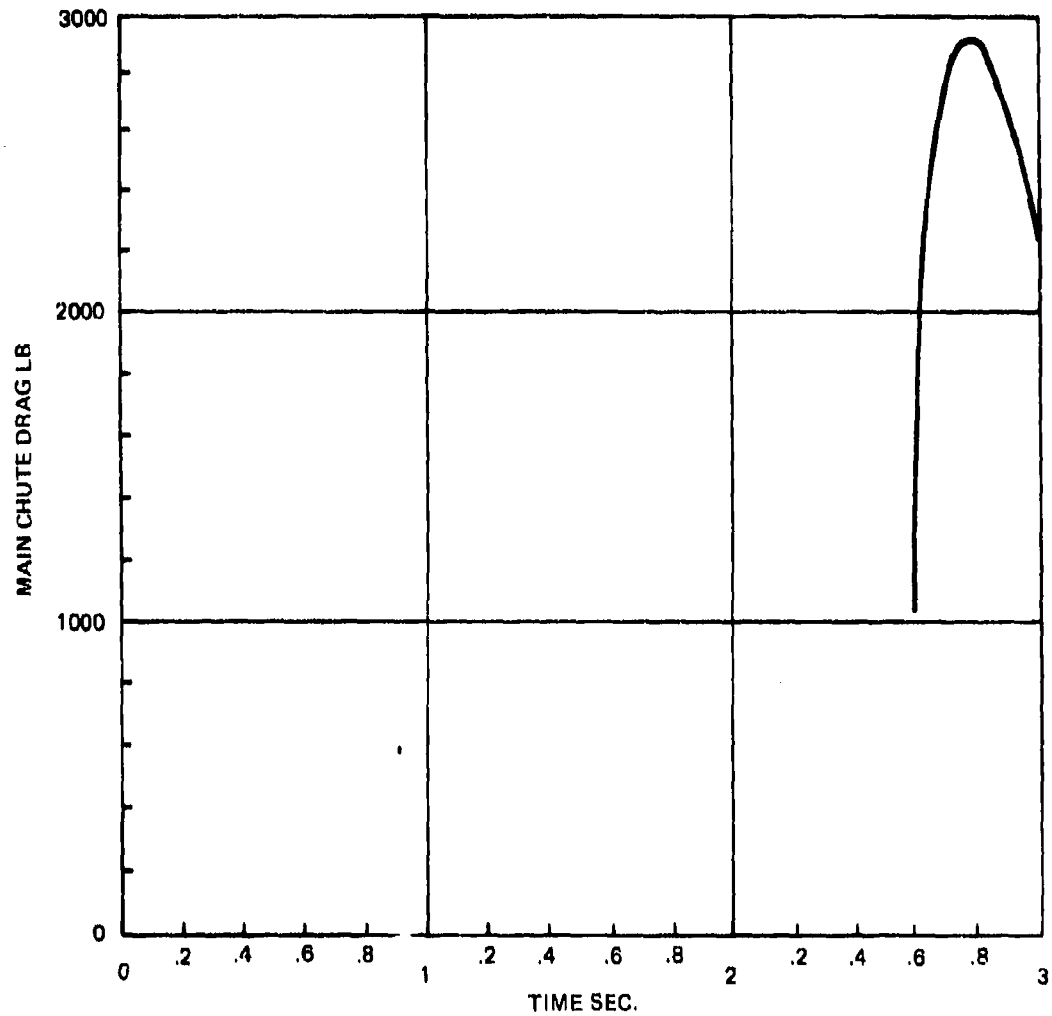


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 4 of 9)

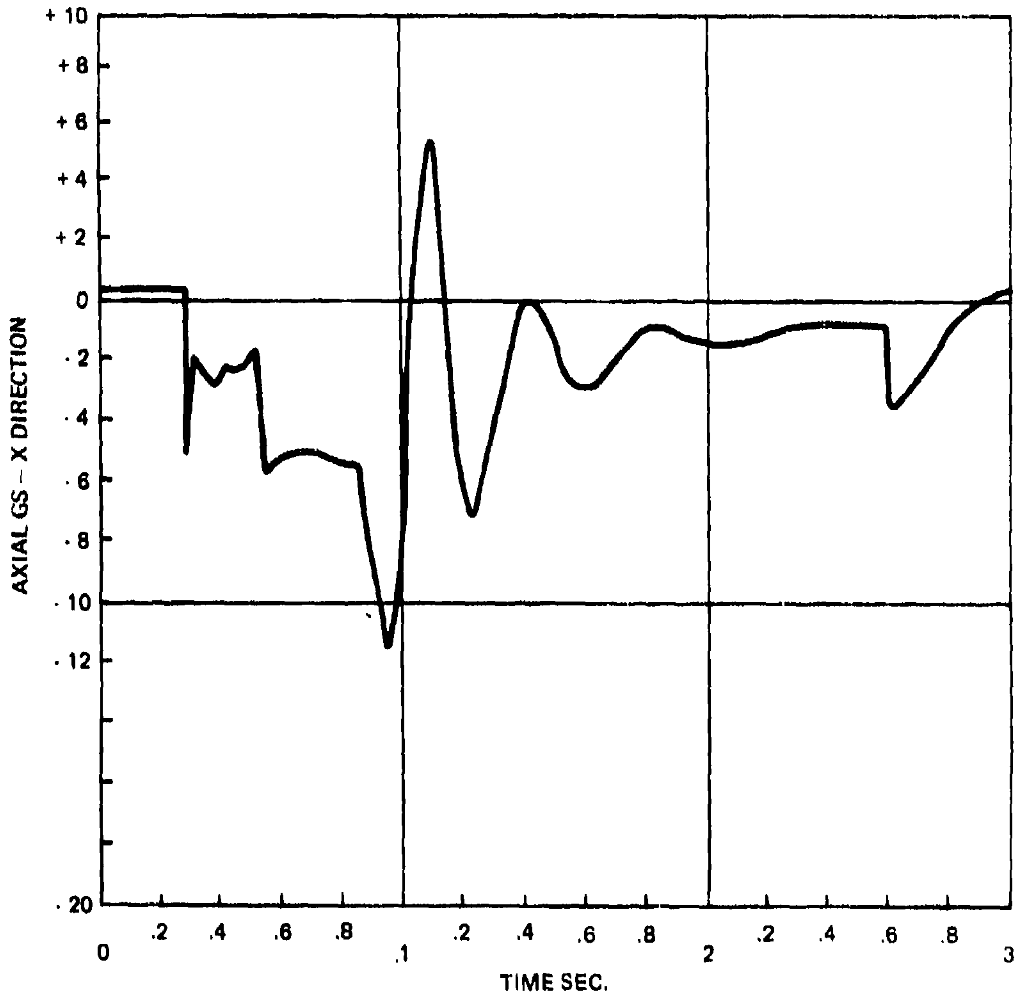


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 5 of 9)

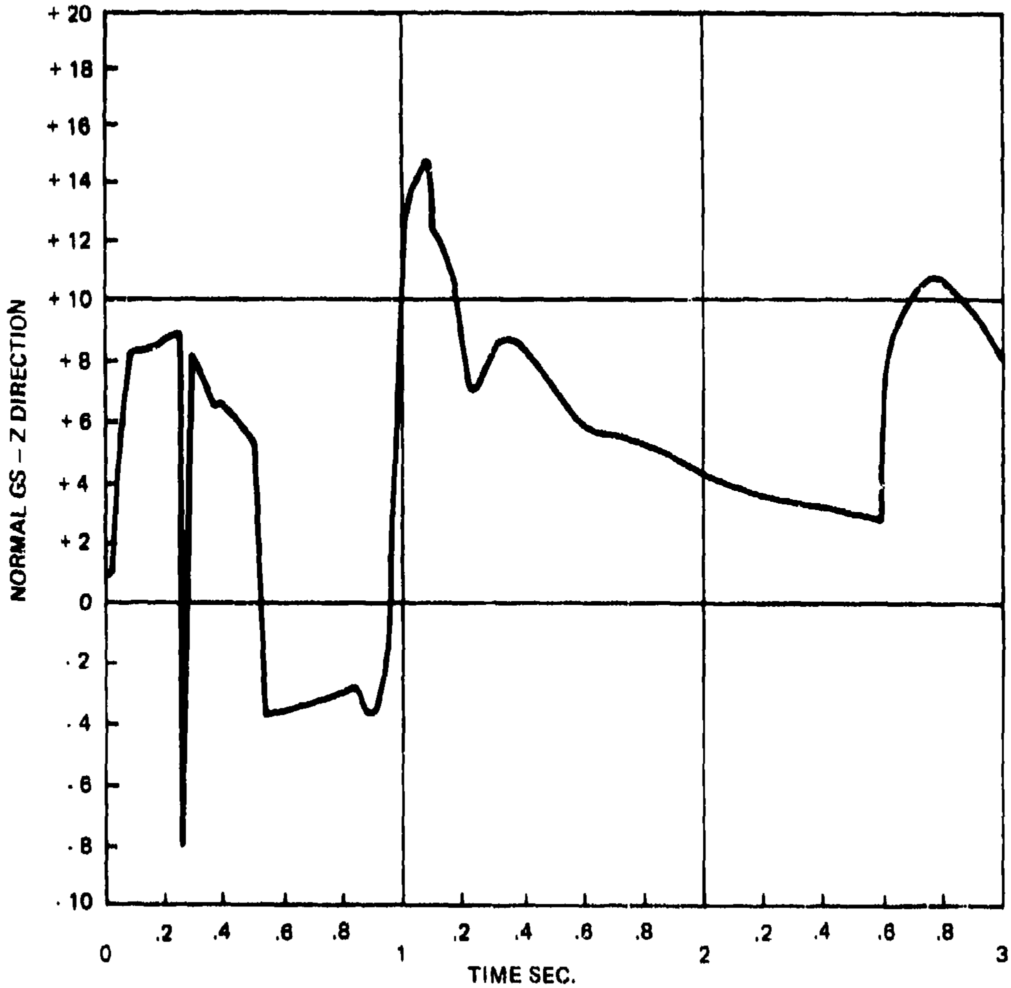


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 6 of 9)

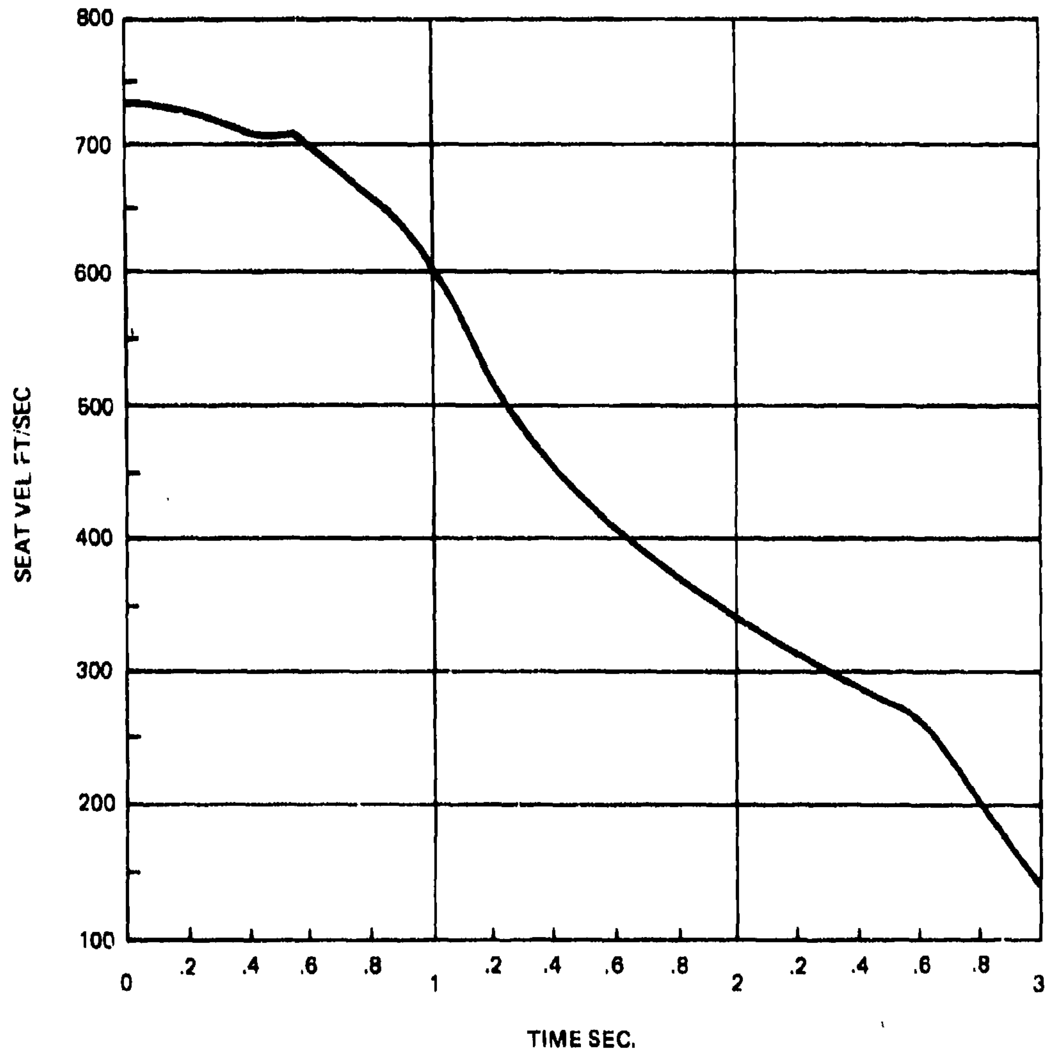


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 7 of 9)

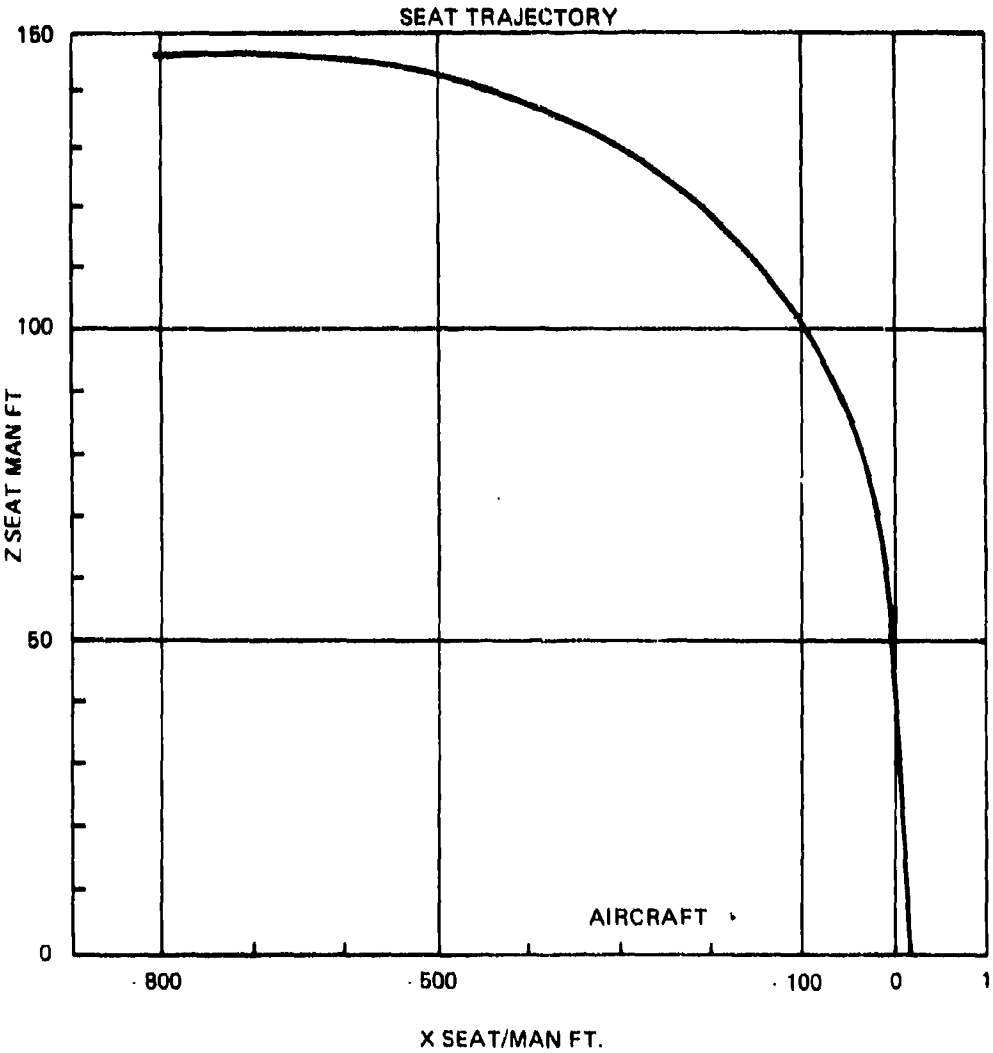


Figure 49 Computer Run - 435 KTS. S. L. MK-GRU7 Type Seat (Sheet 8 of 9)

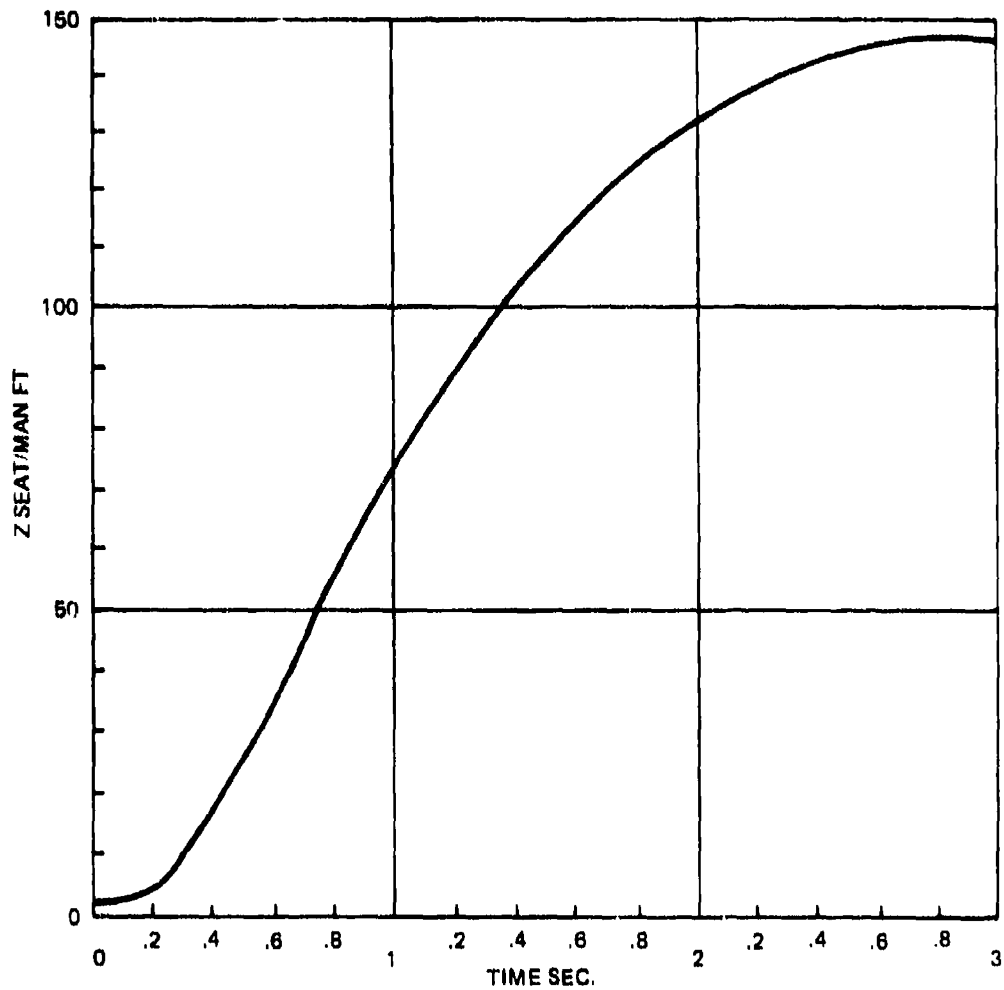


Figure 49 Computer Run - 435 KTS, S. L. MK-GRU7 Type Seat (Sheet 9 of 9)

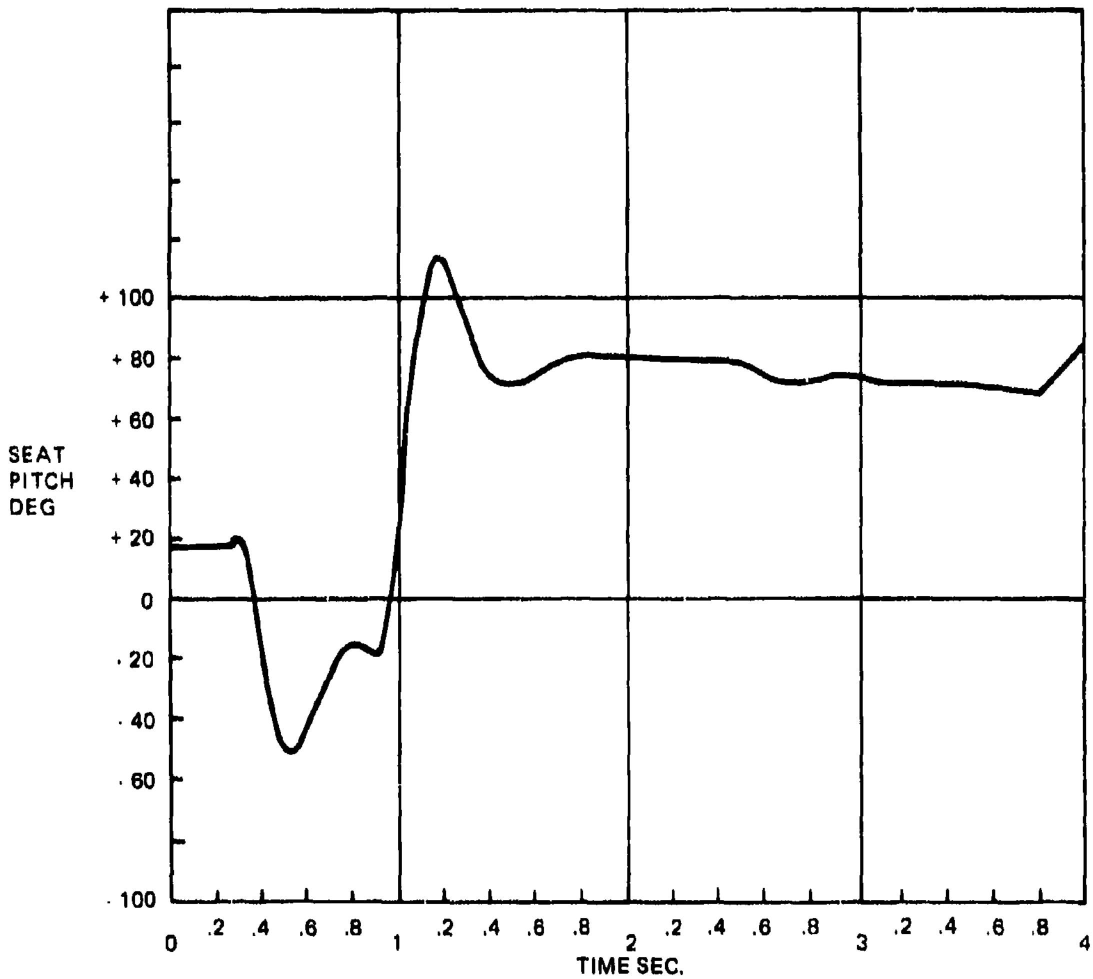


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 1 of 10)

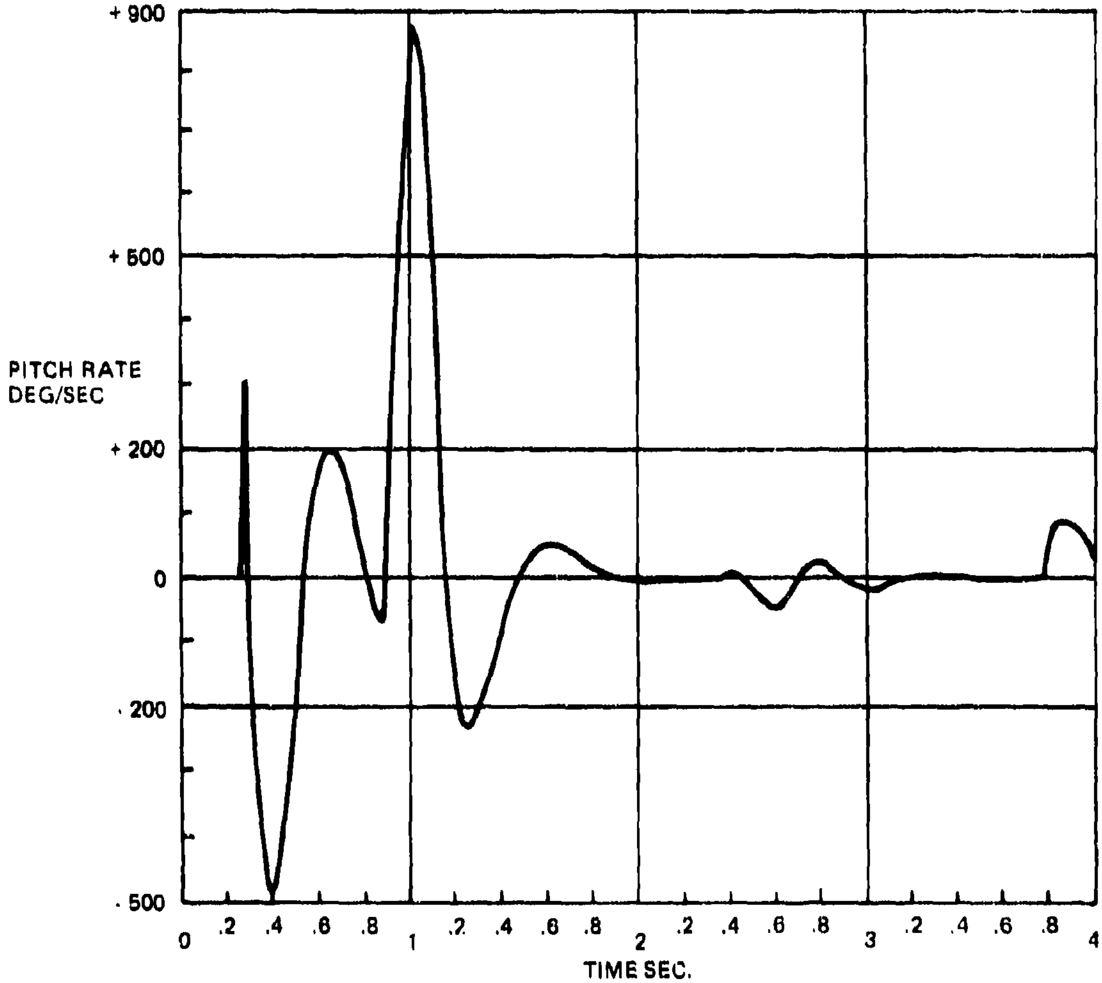


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 2 of 10)

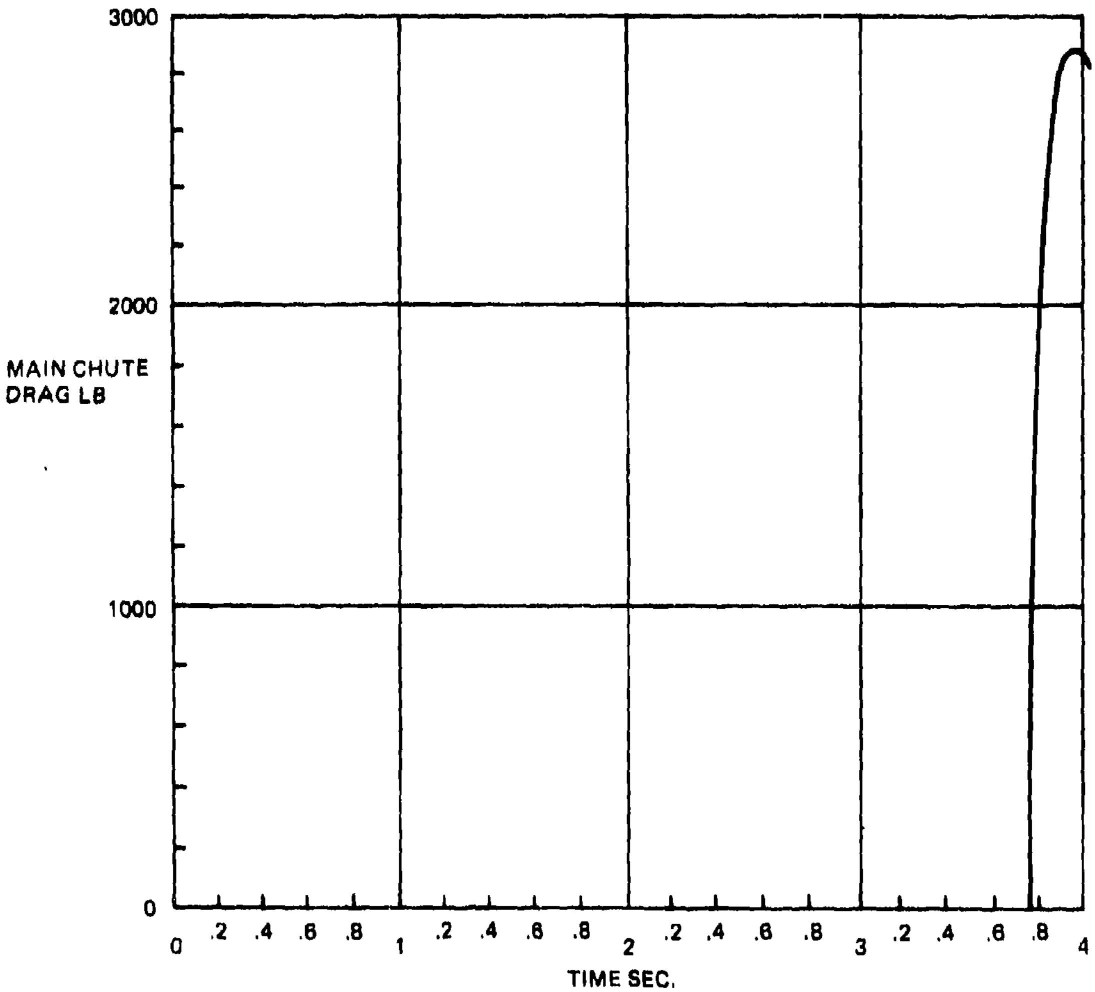


Figure 50 Computer Run -- 600 KTS. S.L. With Two Stage Drogue (Sheet 3 of 10)

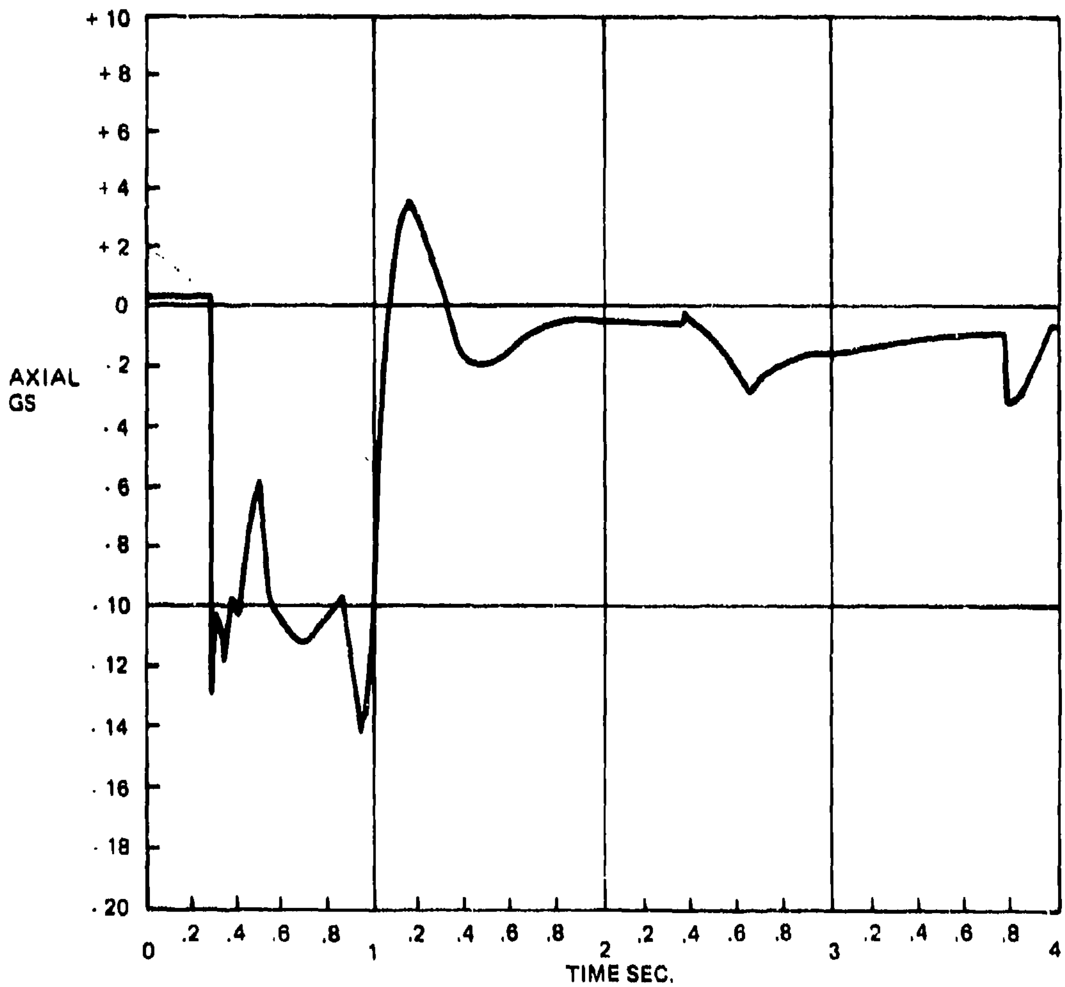


Figure 50 Computer Run — 600 KTS. S.L. With Two Stage Drogue (Sheet 4 of 10)

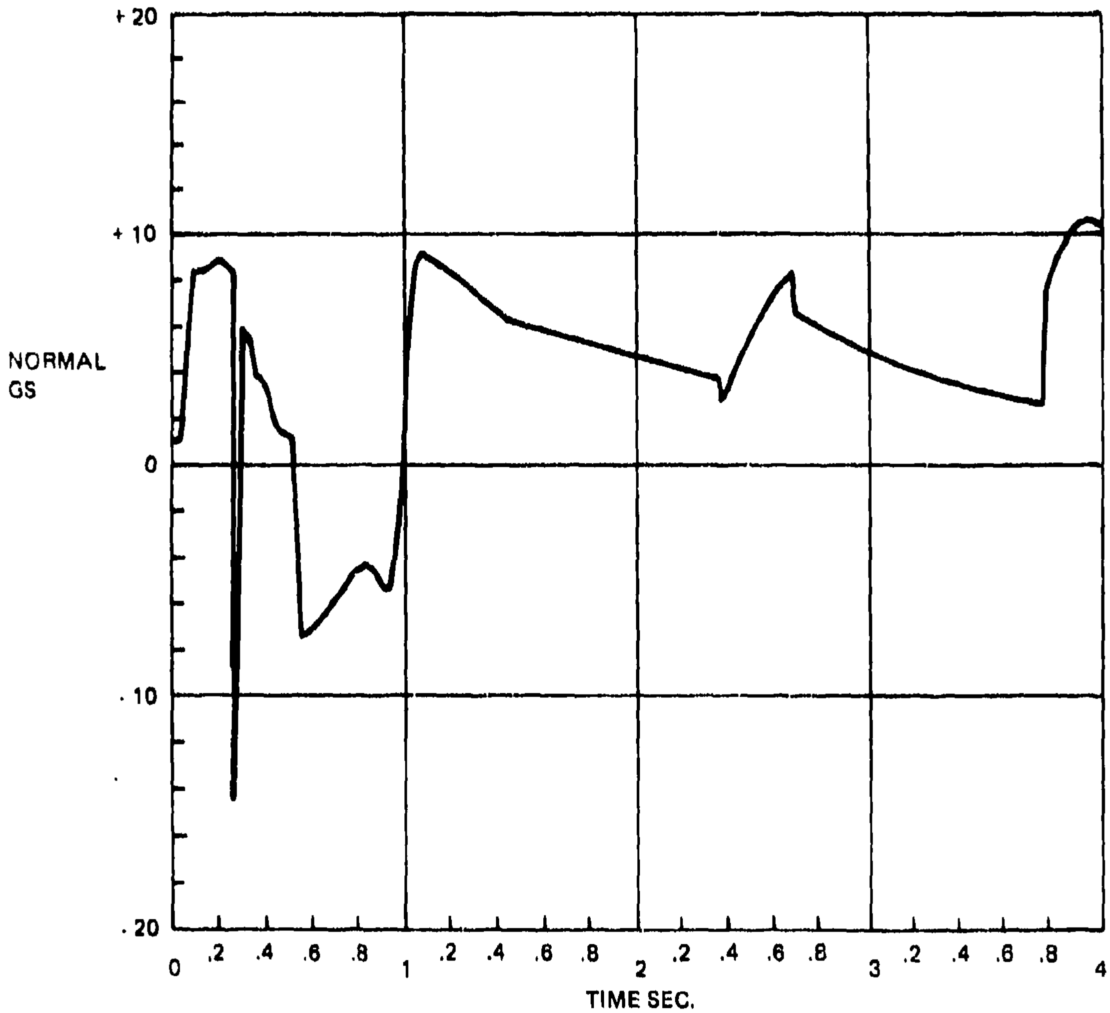


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 5 of 10)

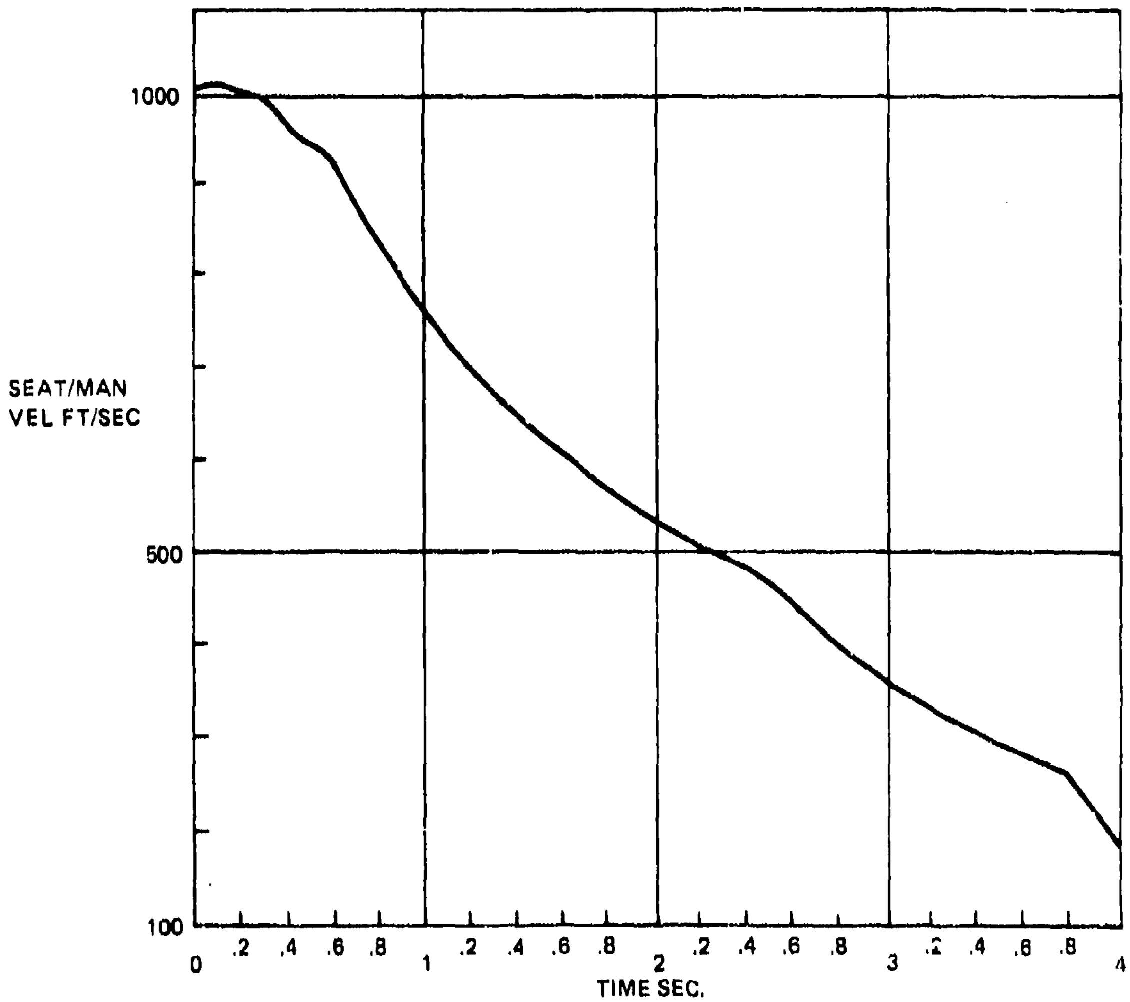


Figure 50 Computer Run — 600 KTS. S.L. With Two Stage Drogue (Sheet 6 of 10)

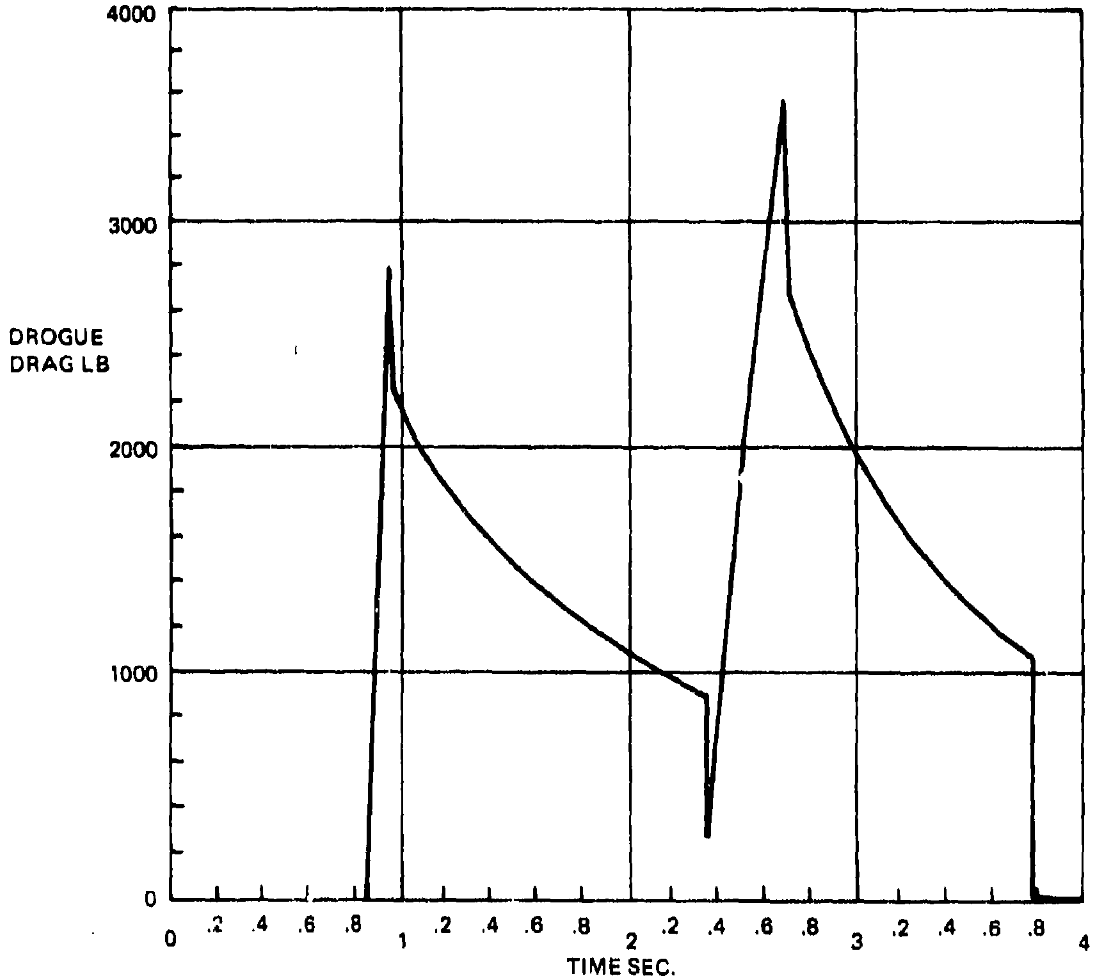


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 7 of 10)

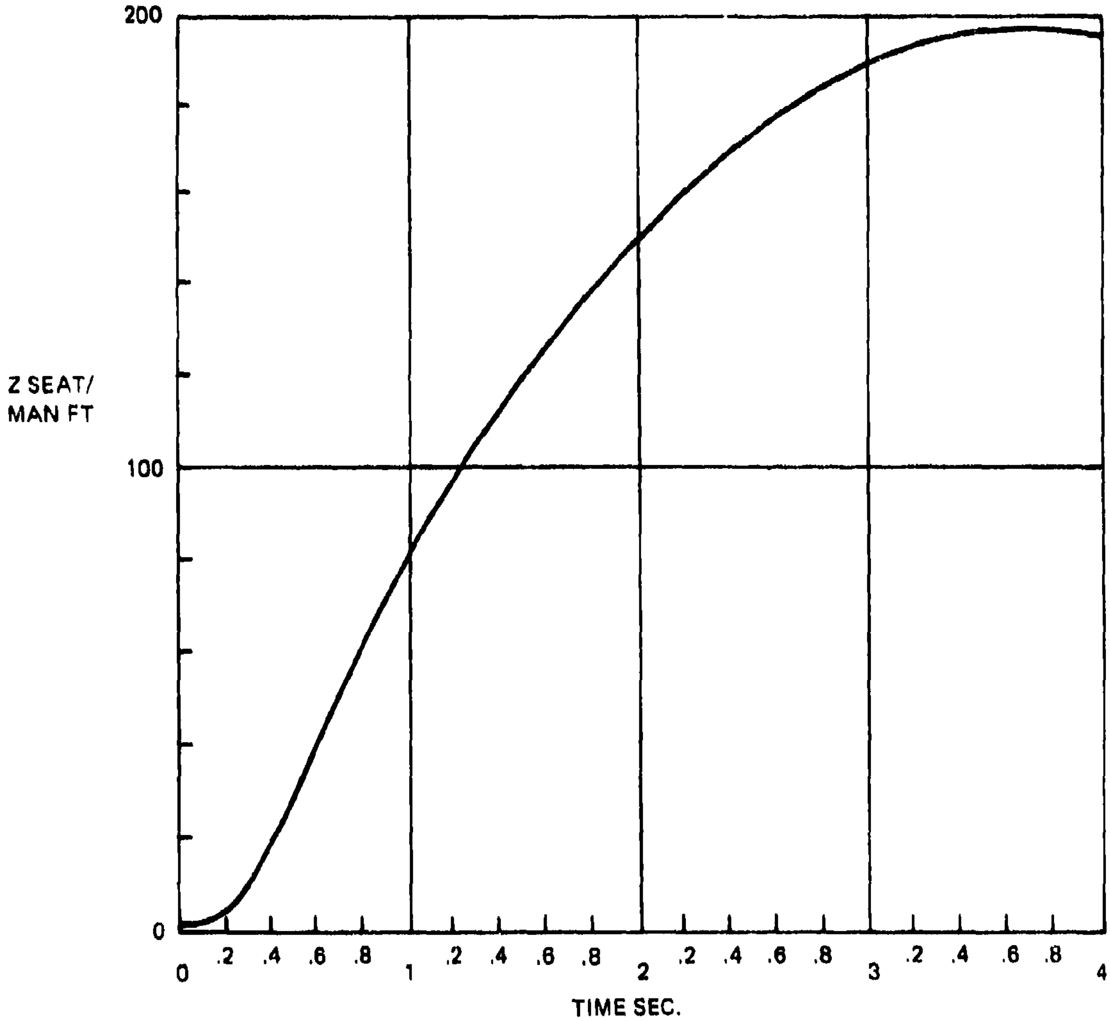


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 8 of 10)

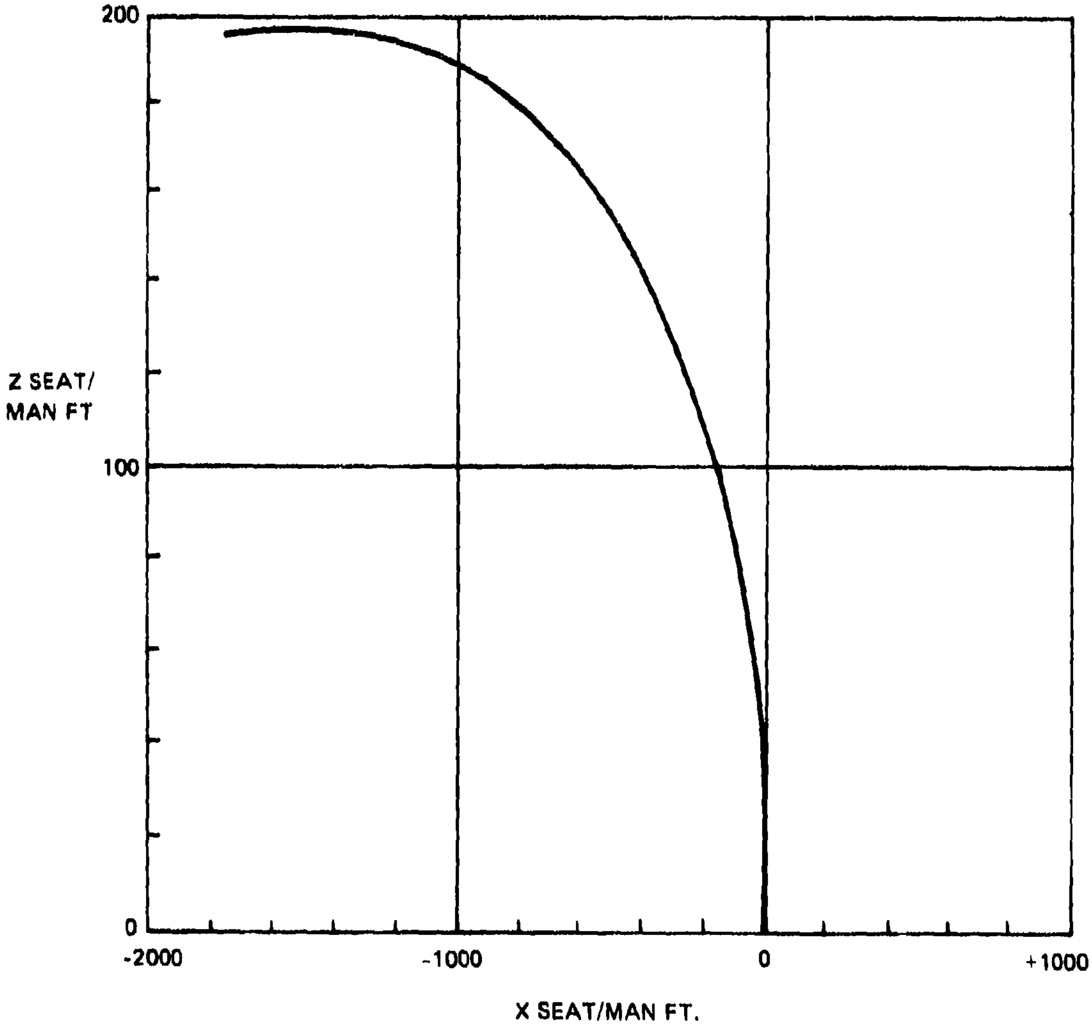


Figure 50 Computer Run – 600 KTS. S.L. With Two Stage Drogue (Sheet 9 of 10)

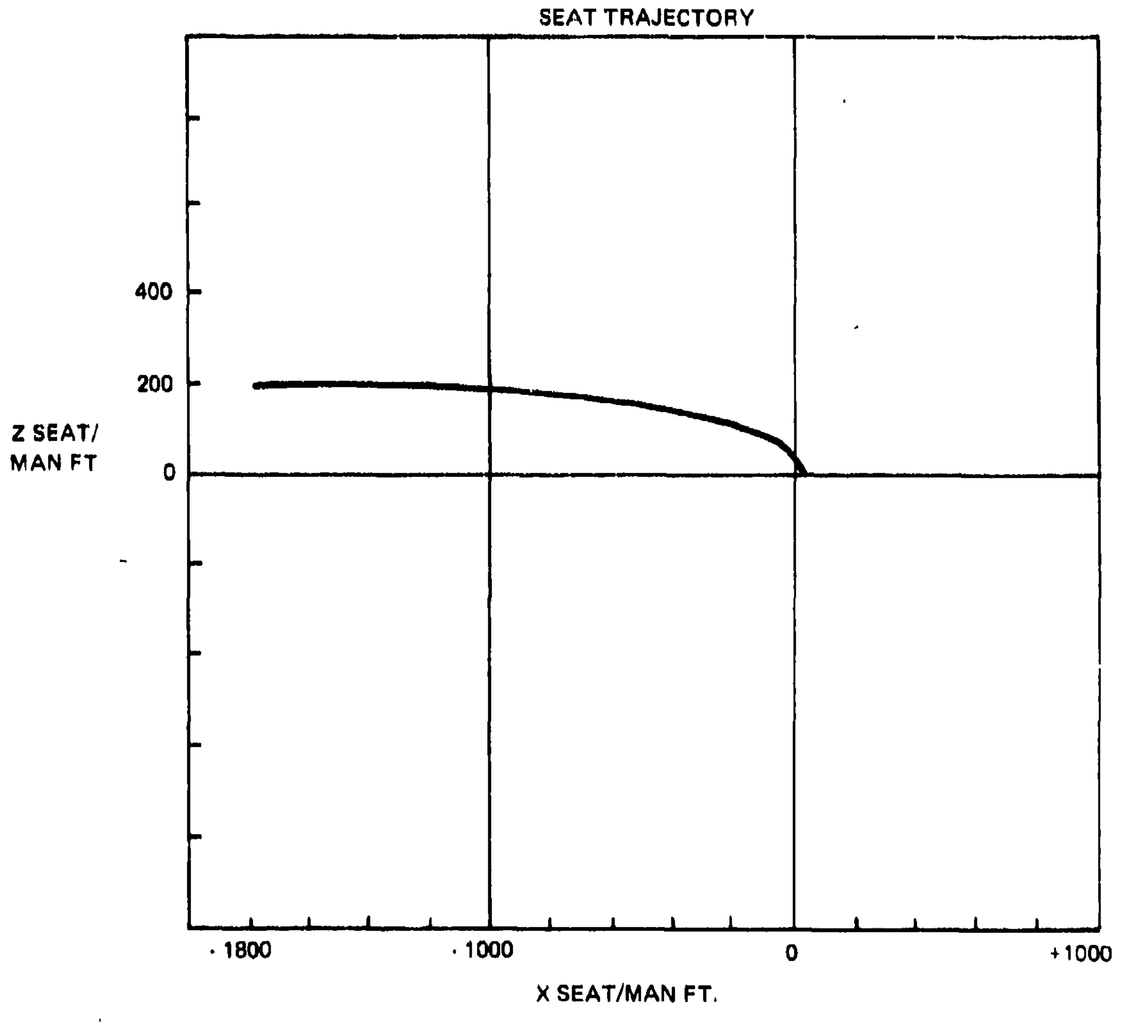


Figure 50 Computer Run — 600 KTS. S.L. With Two Stage Drogue (Sheet 10 of 10)

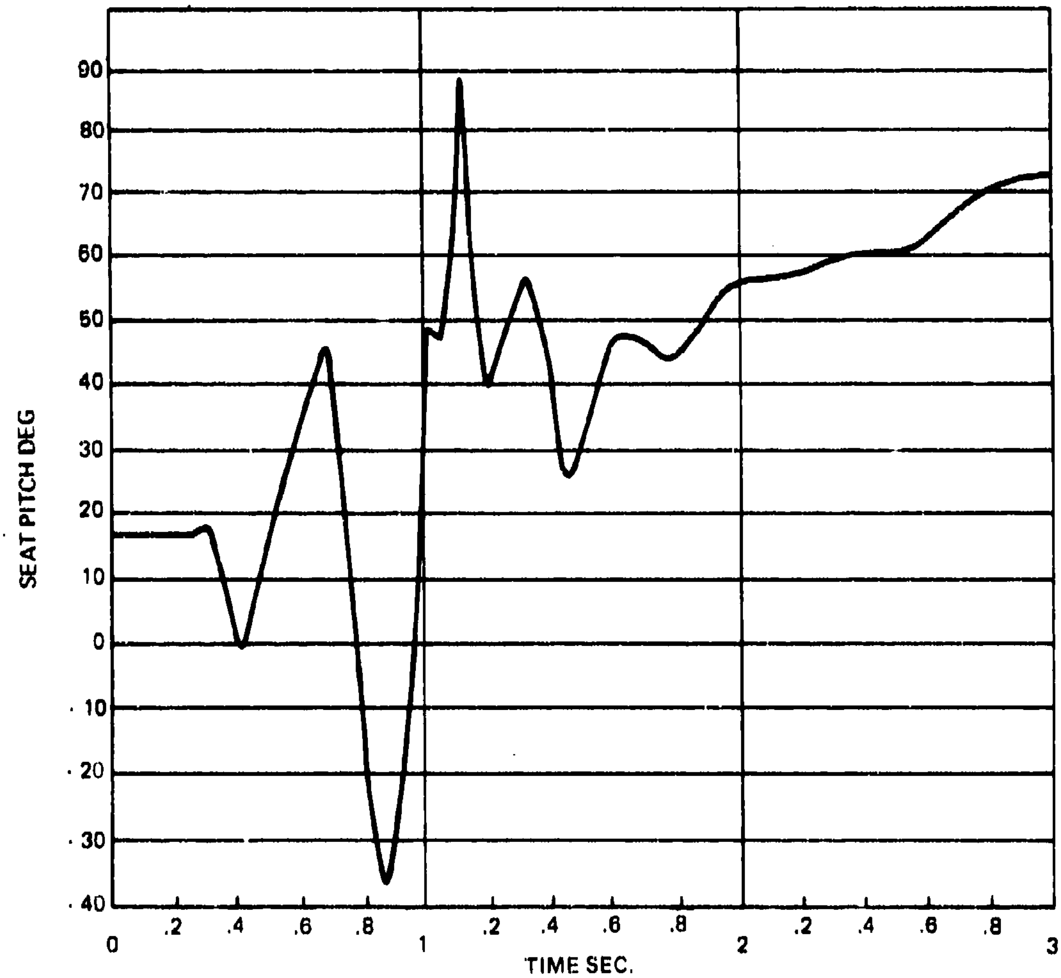


Figure 51 Computer Run -- 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 1 of 9)

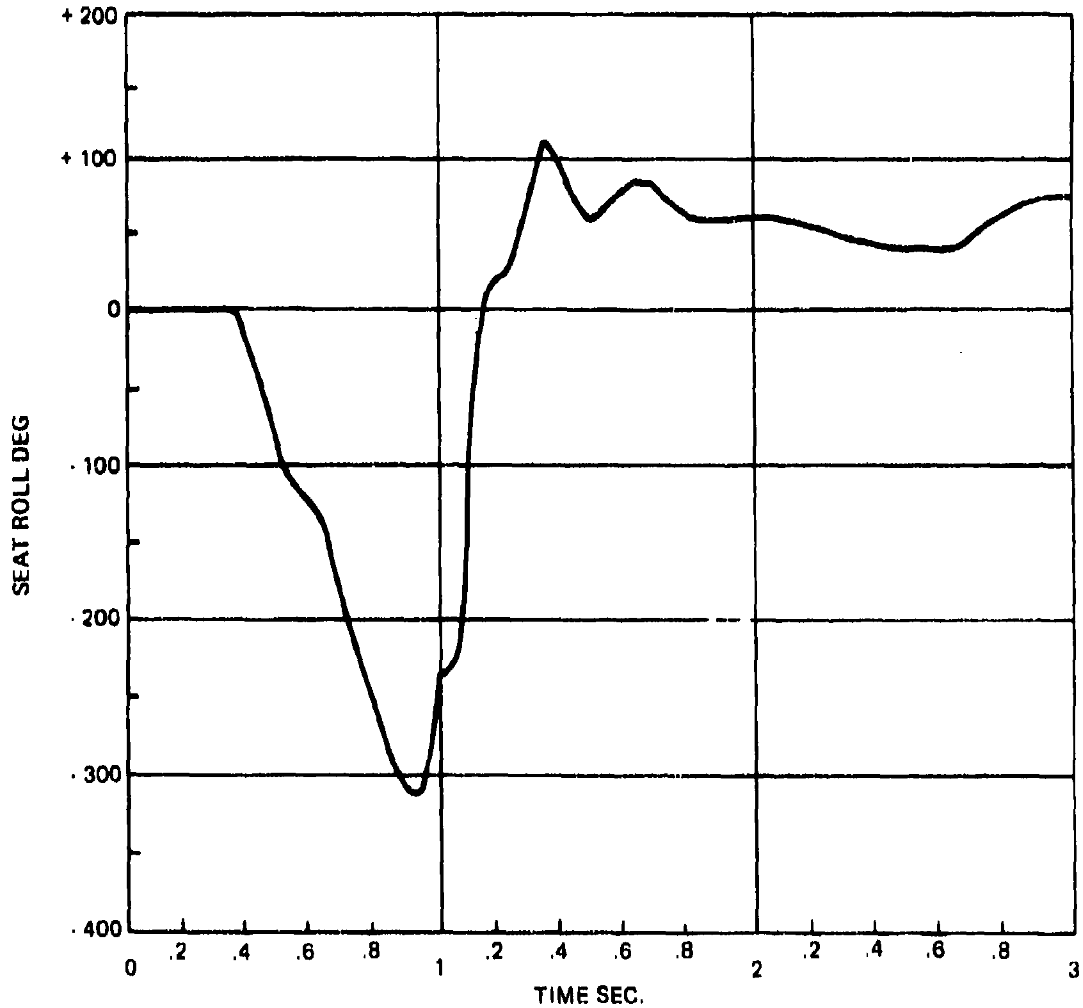


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 2 of 9)

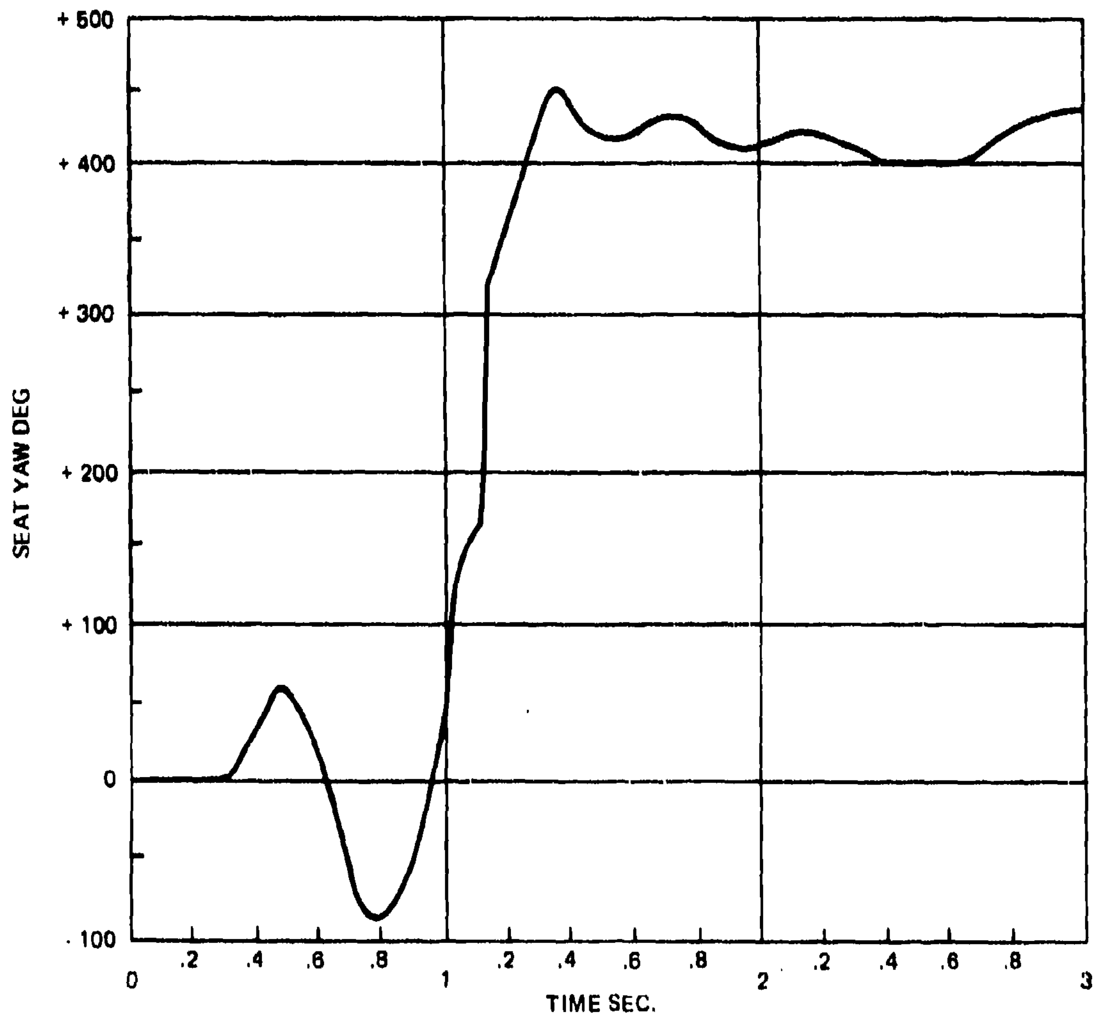


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 3 of 9)

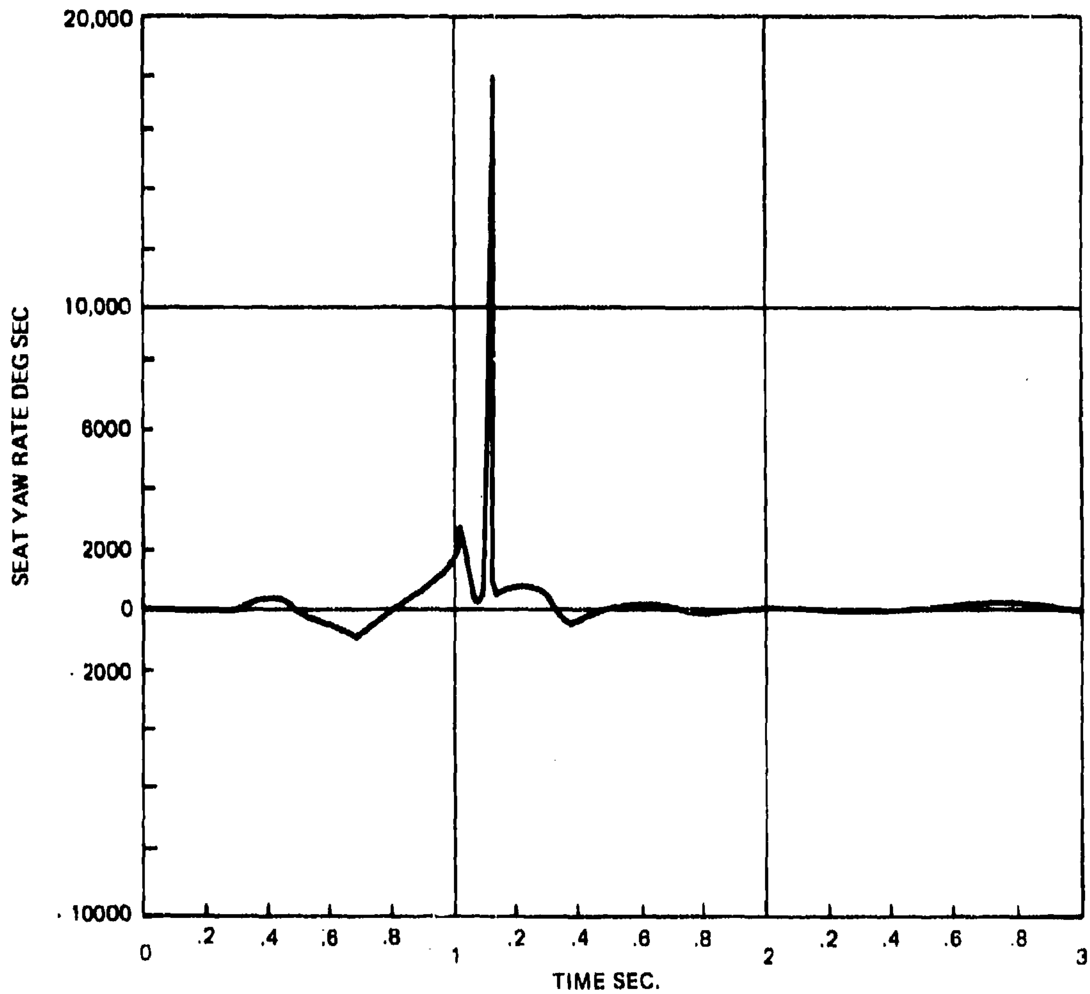


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 4 of 9)

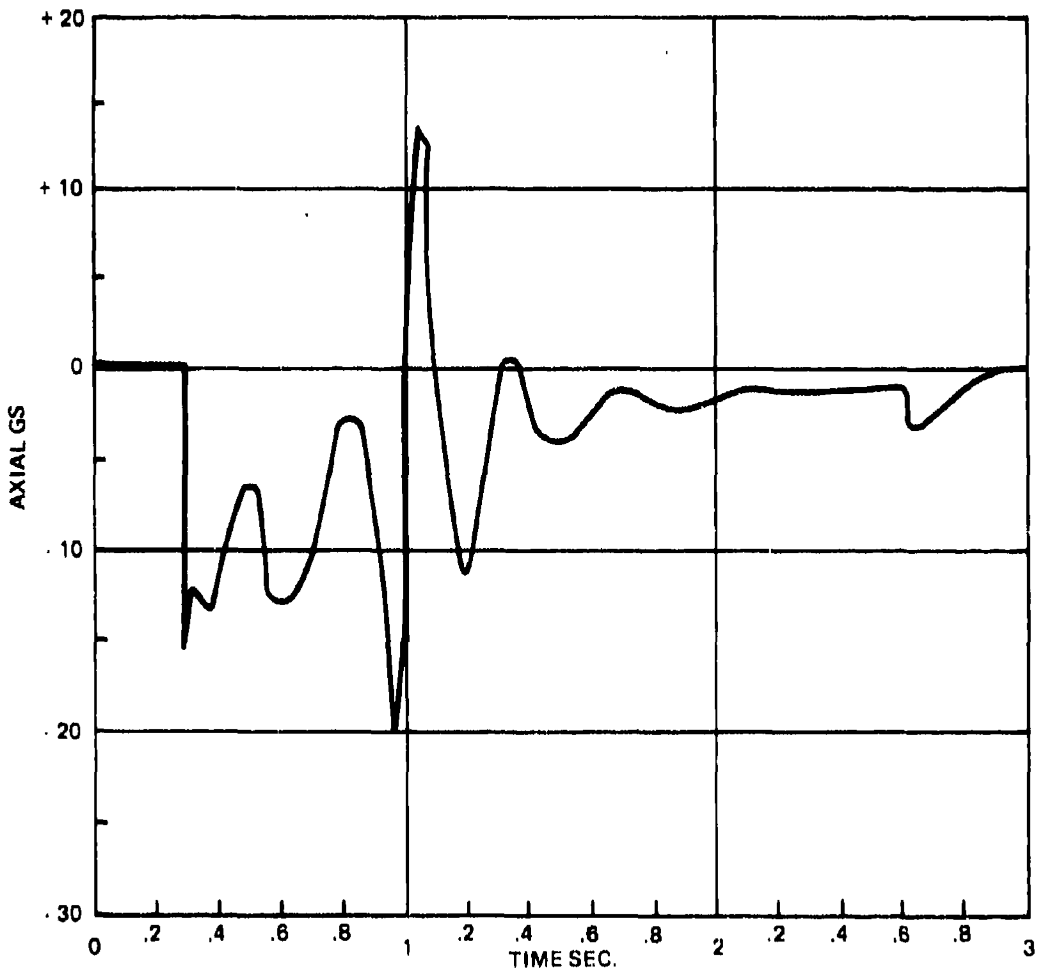


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 5 of 9)

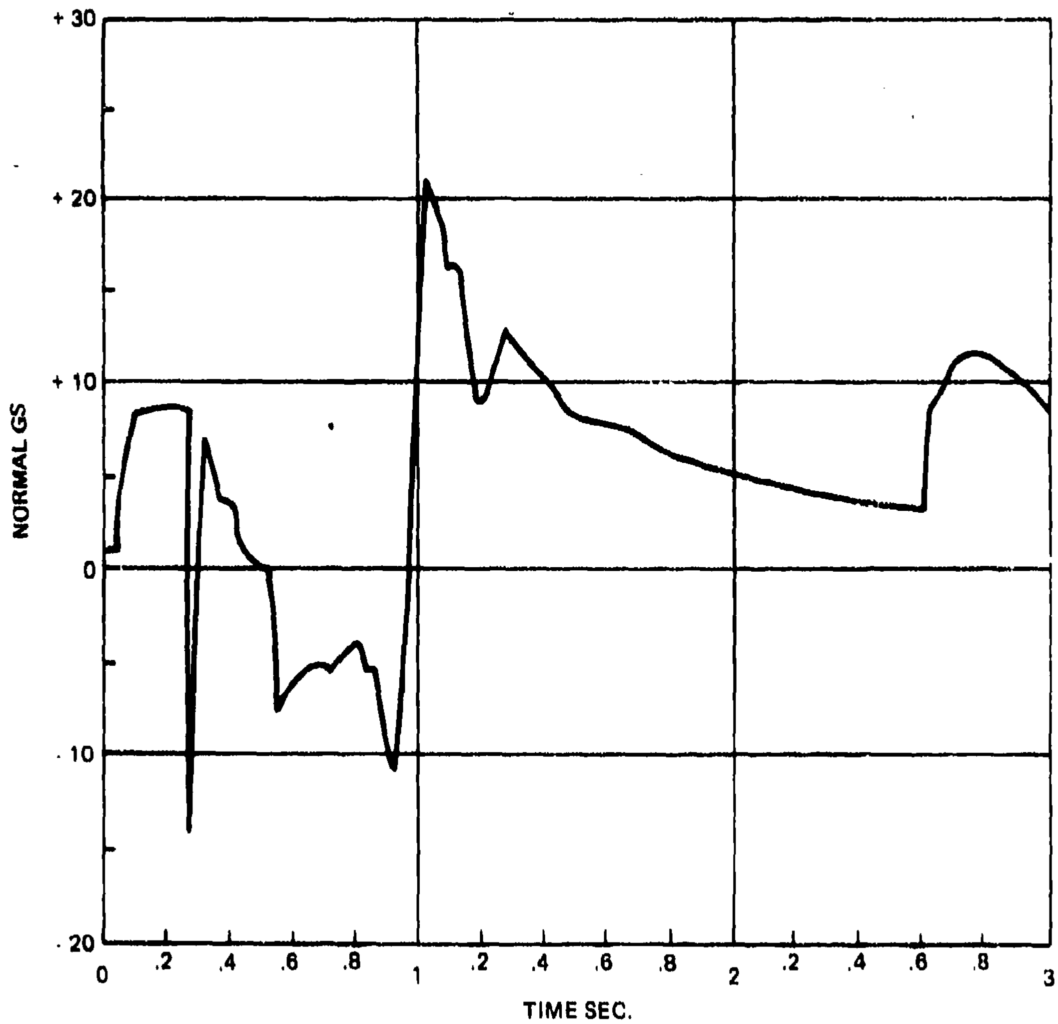


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 6 of 9)

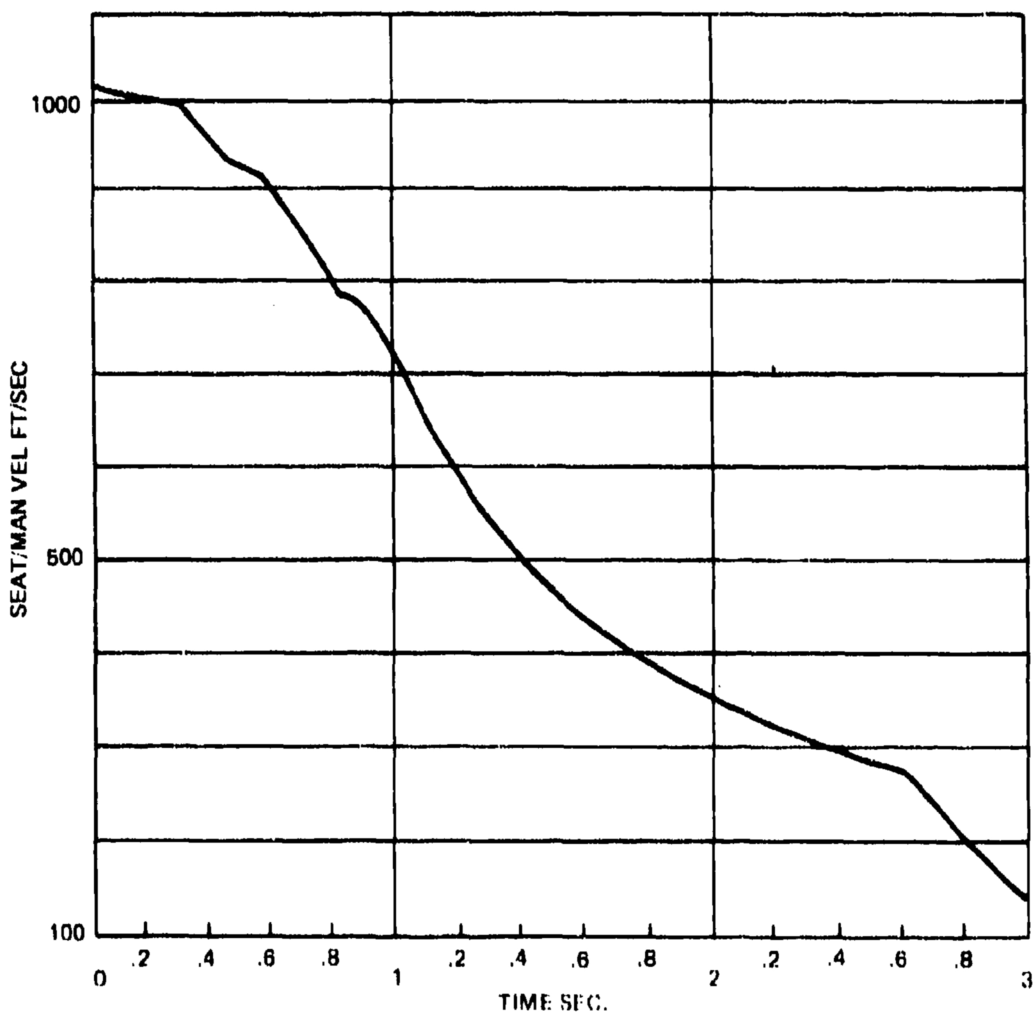


Figure 51 Computer Run -- 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 7 of 9)

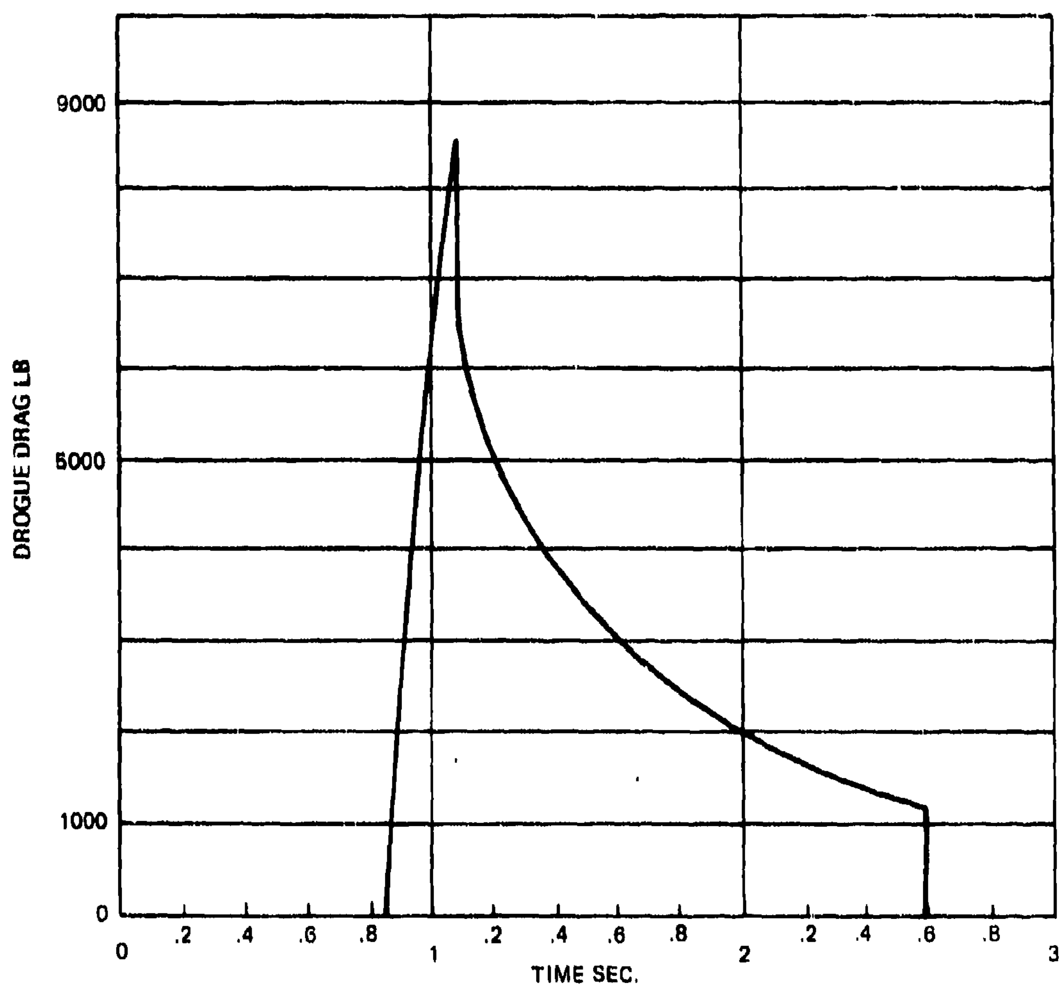


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 8 of 9)

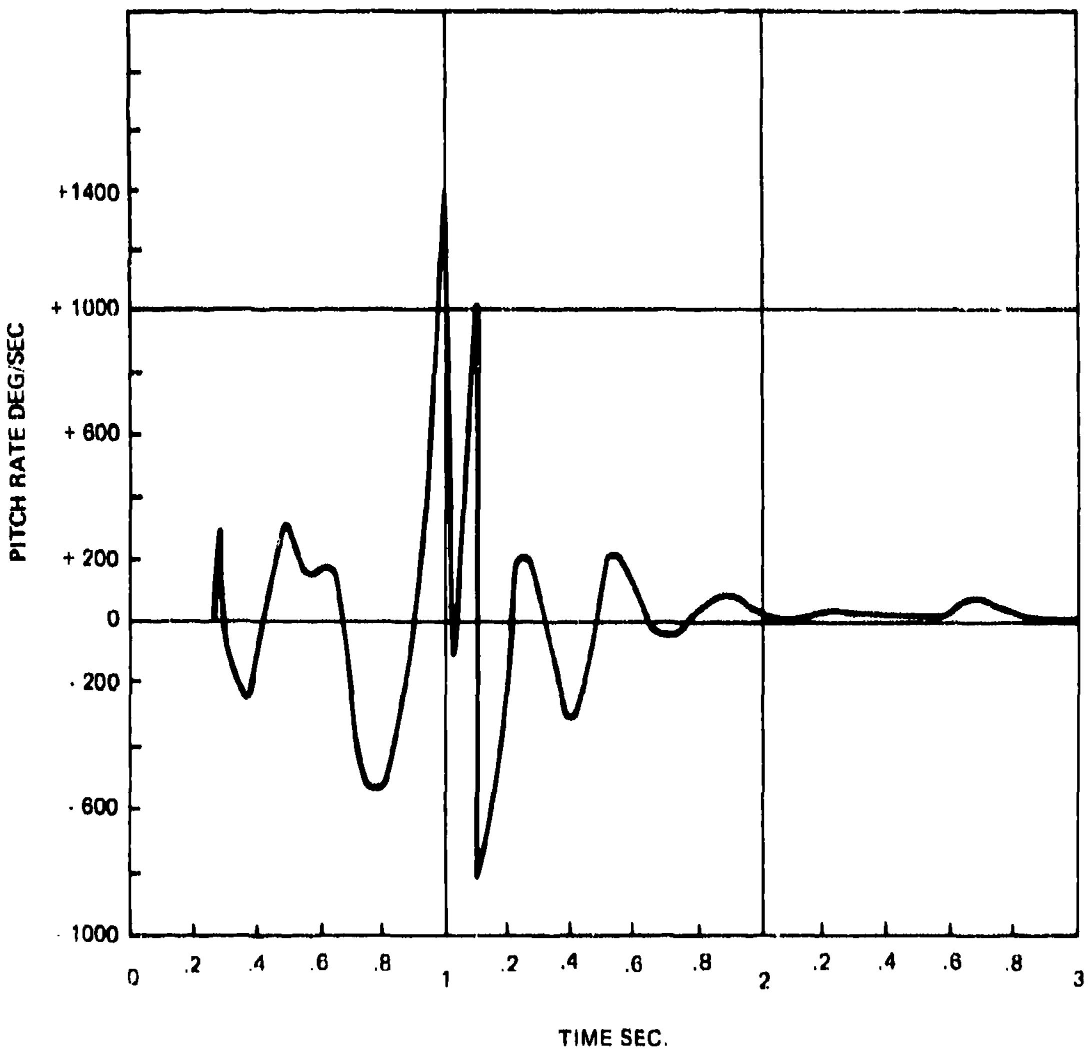


Figure 51 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 4 (Sheet 9 of 9)

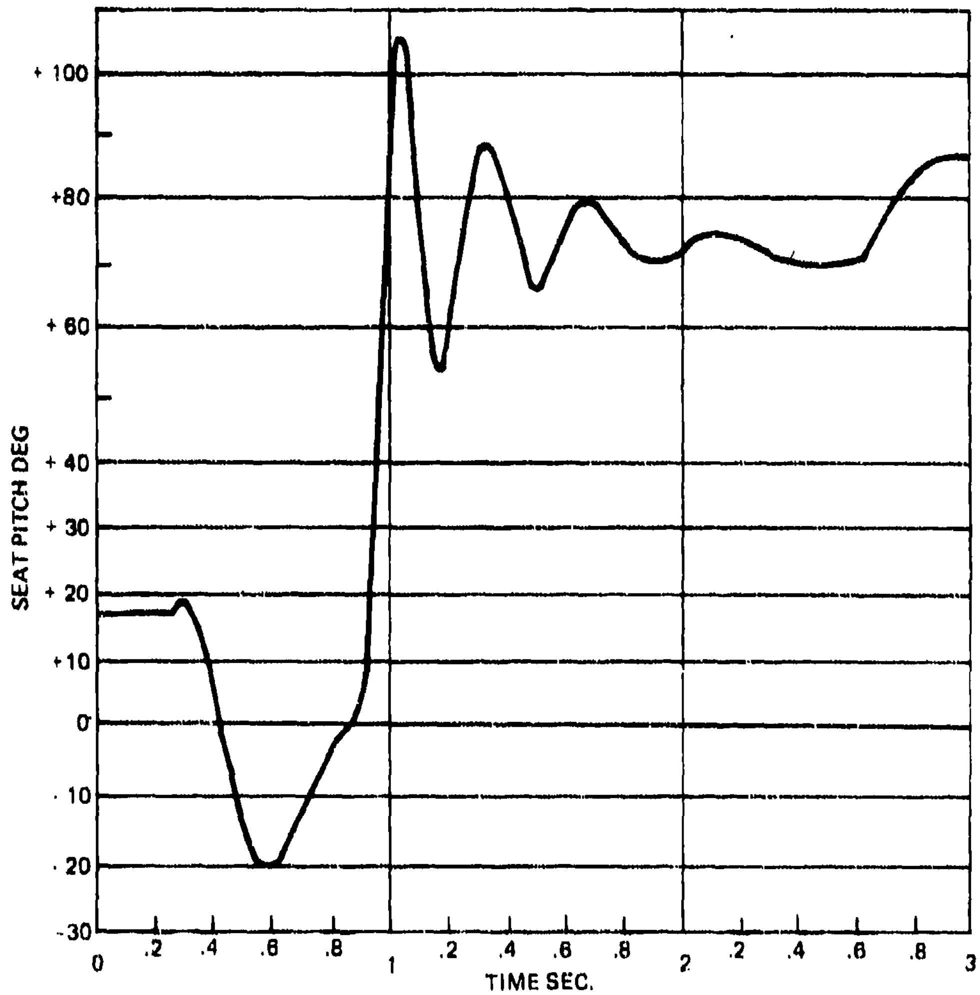


Figure 52 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 5 (Sheet 1 of 5)

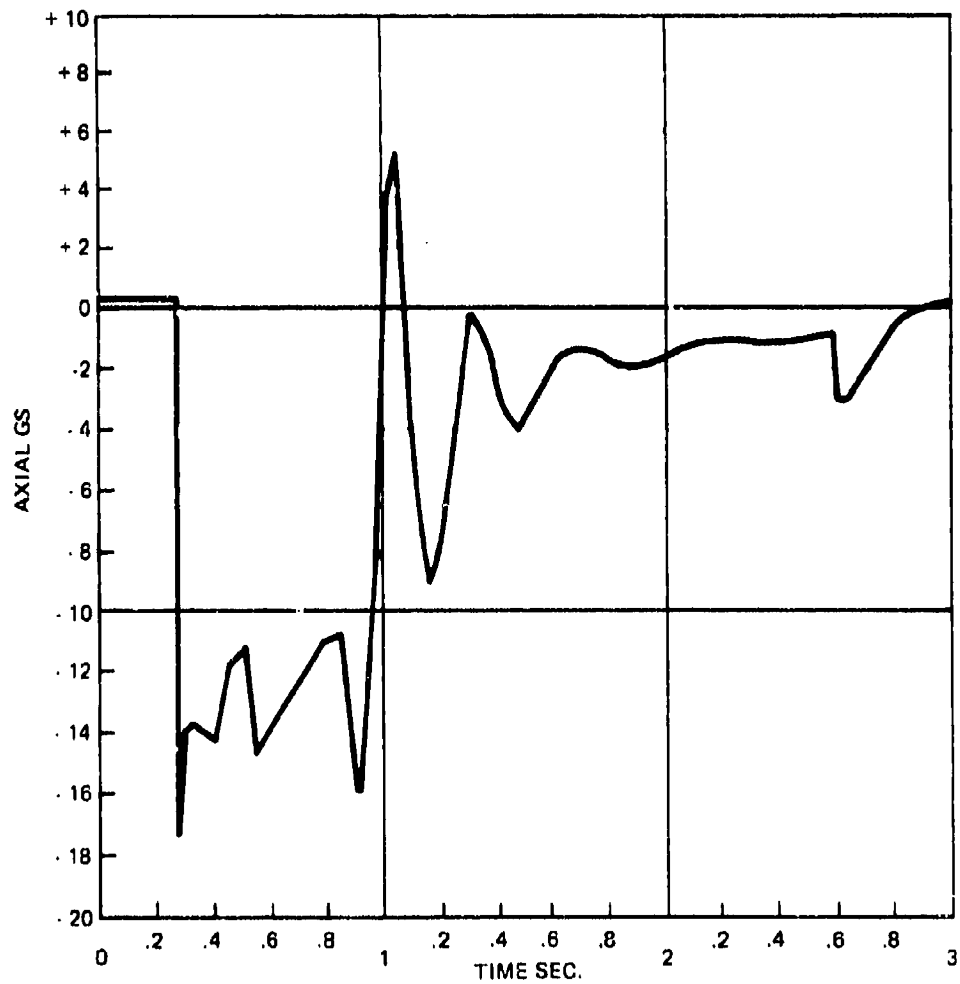


Figure 52 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 5 (Sheet 2 of 5)

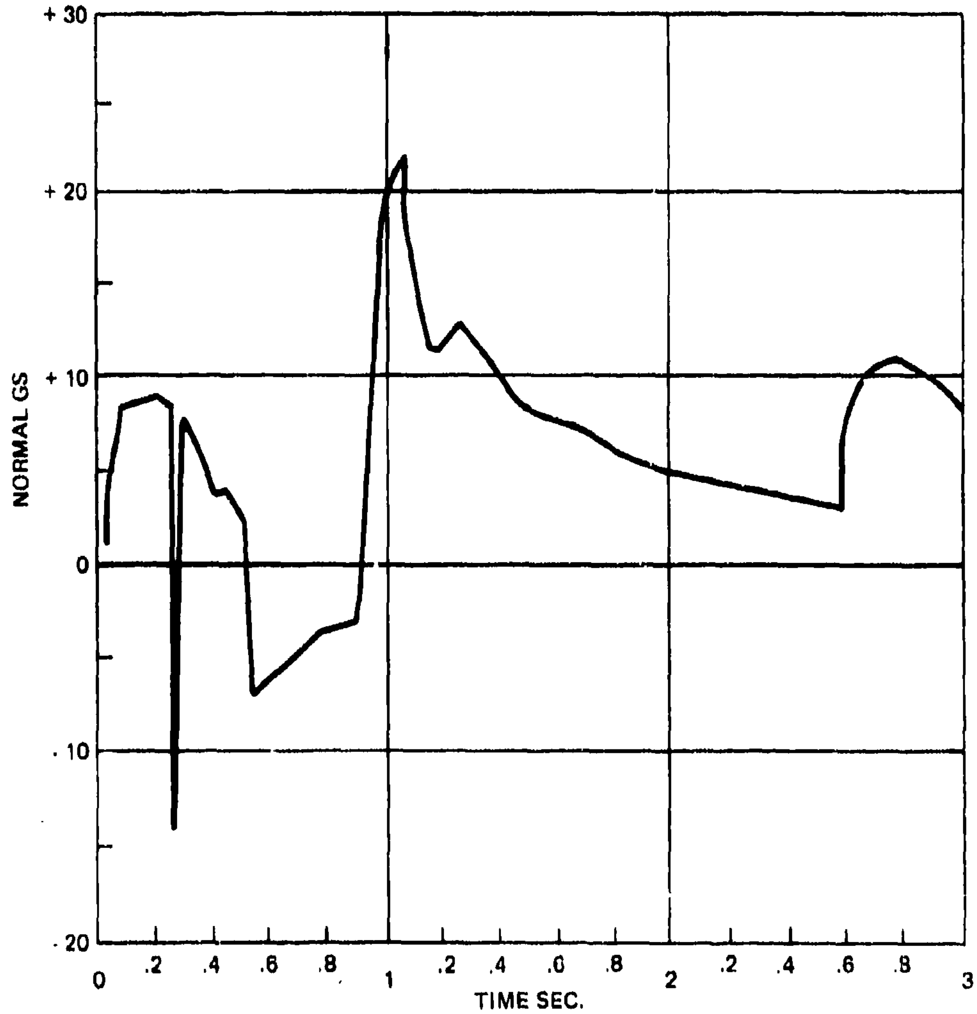


Figure 52 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 5 (Sheet 3 of 5)

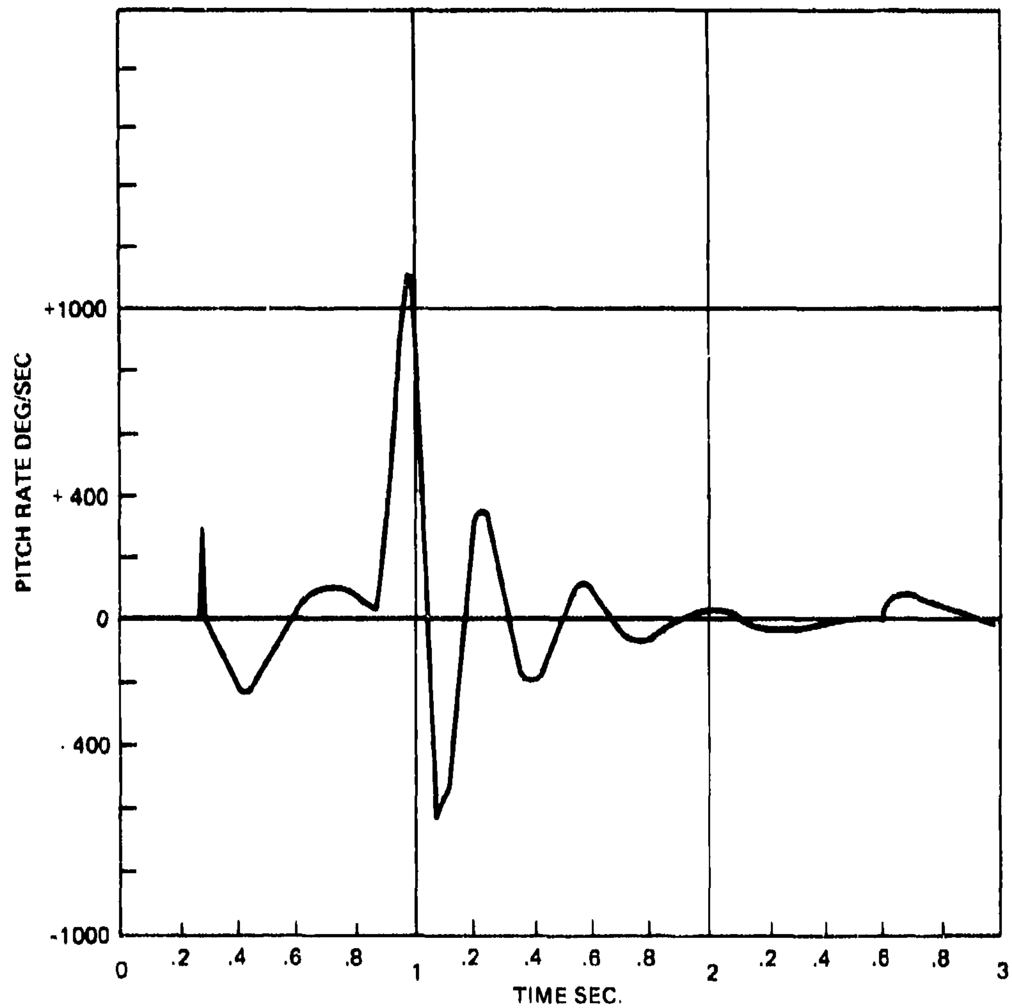


Figure 52 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 5 (Sheet 4 of 6)

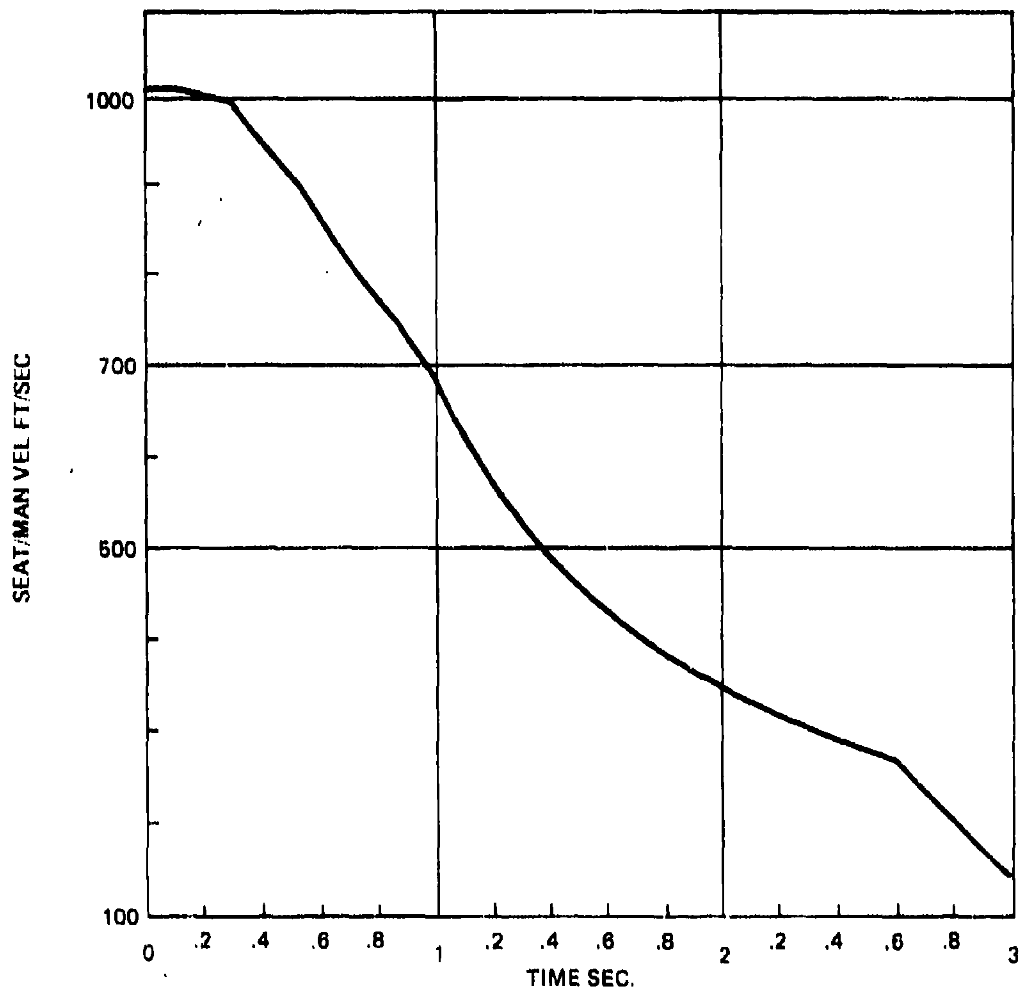


Figure 52 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 5 (Sheet 5 of 5)

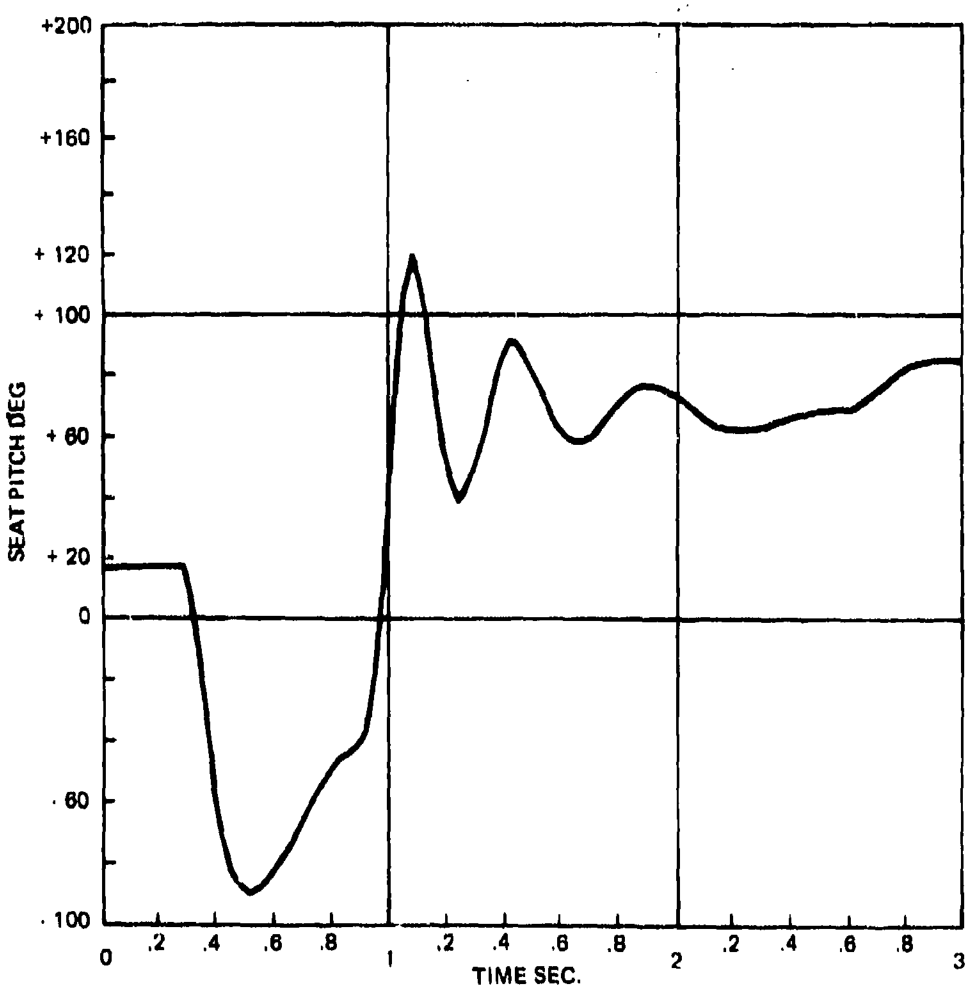


Figure 53 Computer Run — 600 KTS. S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 1 of 6)

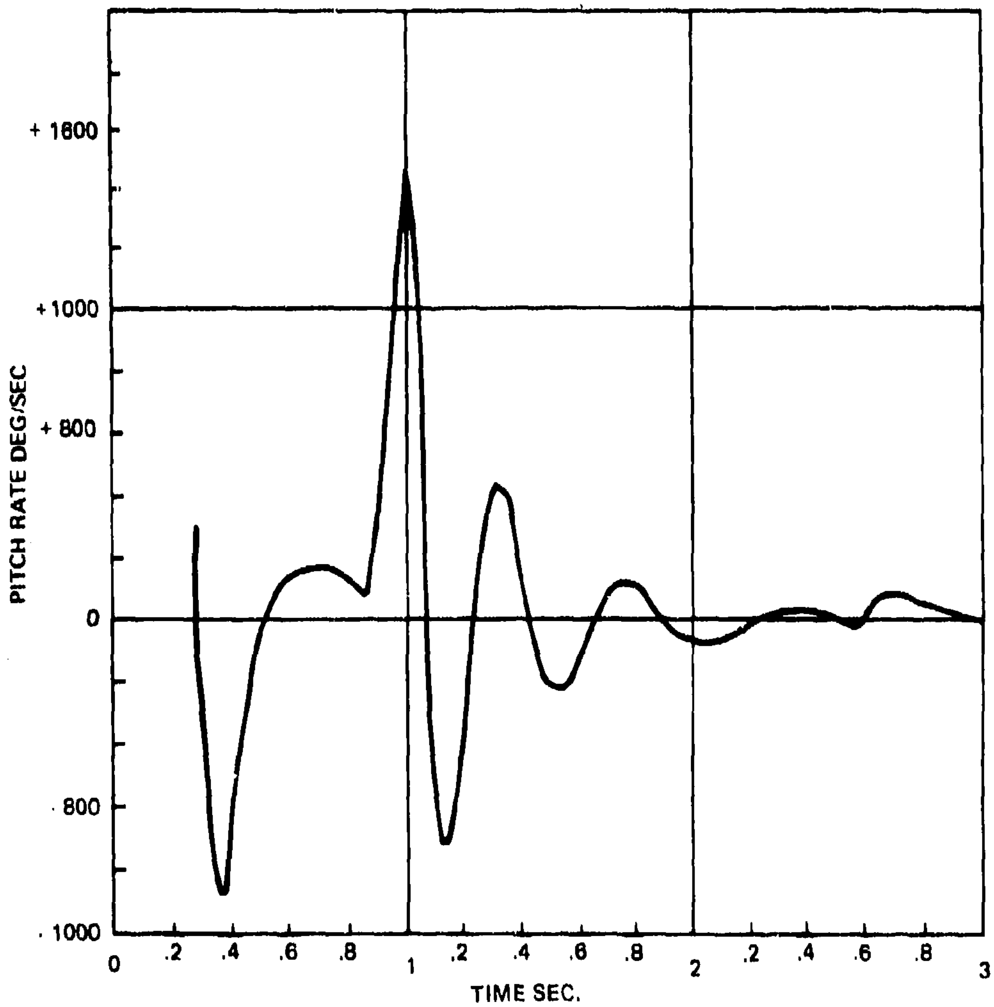


Figure 53 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 2 of 6)

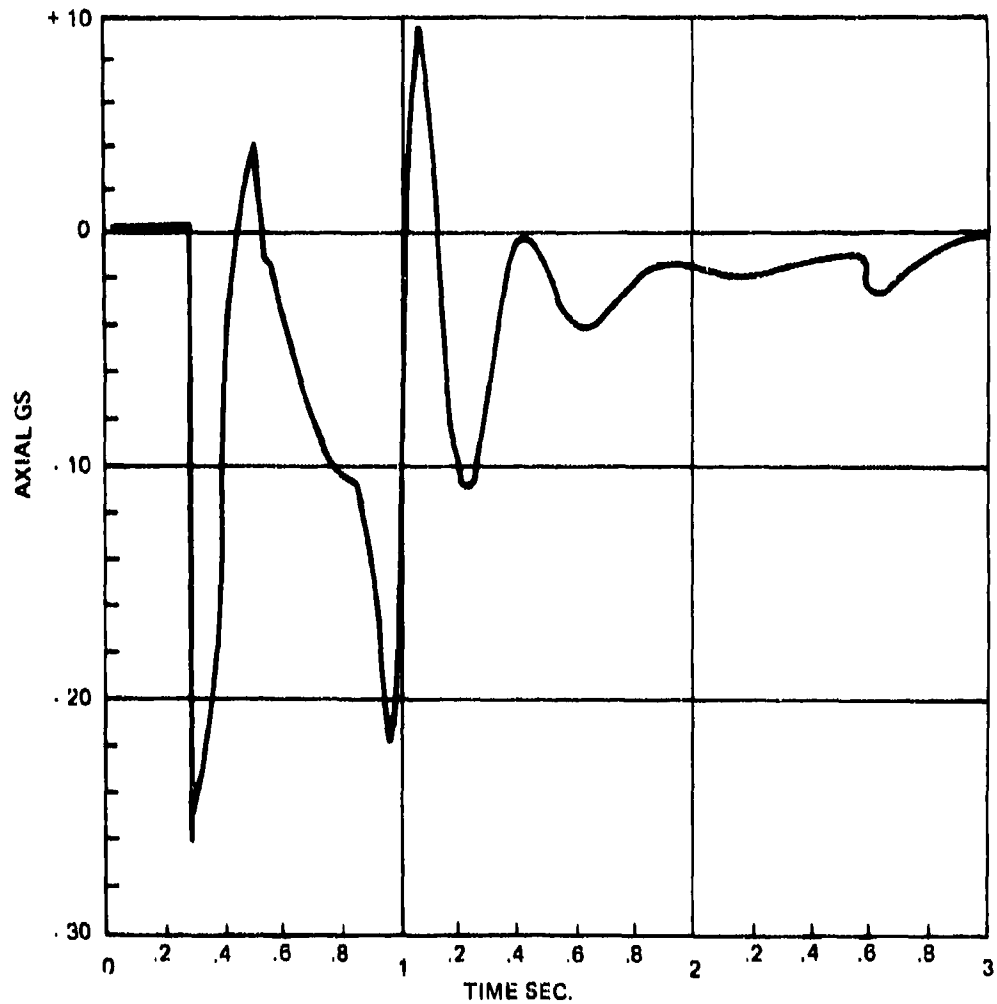


Figure 53 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 3 of 6)

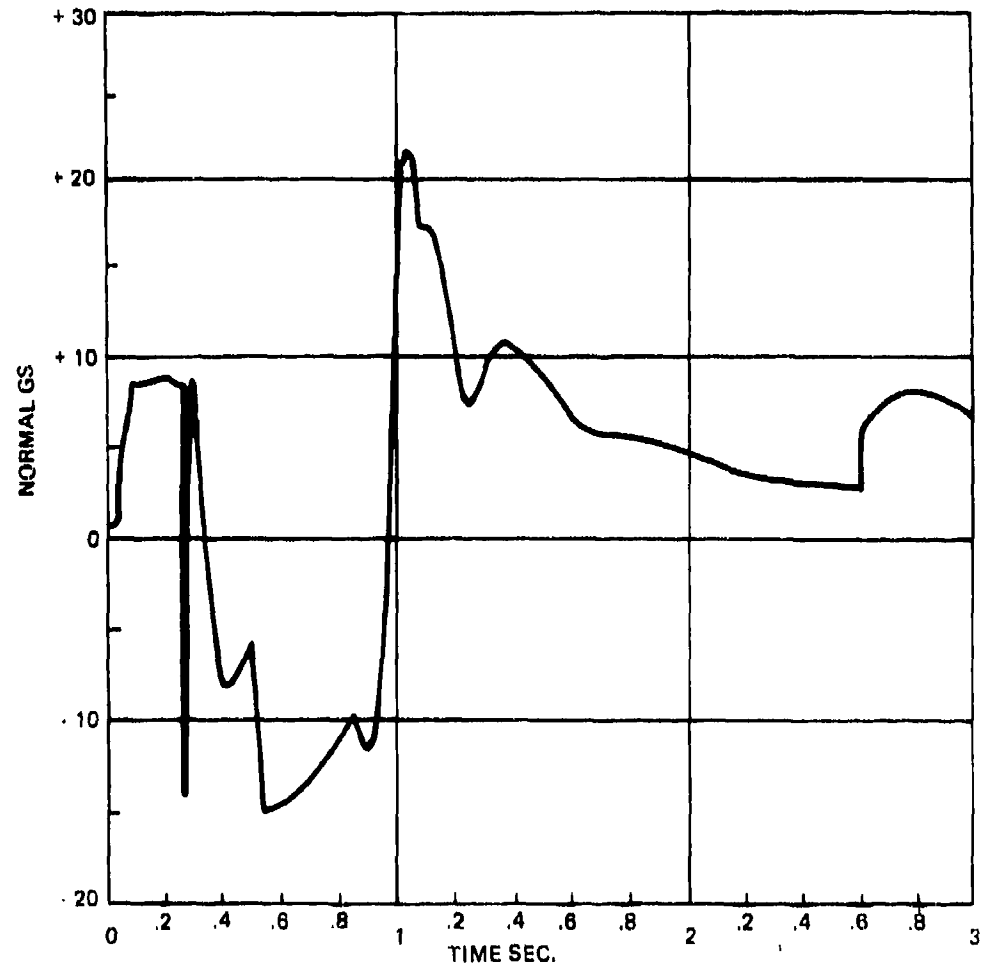


Figure 53 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 4 of 6)

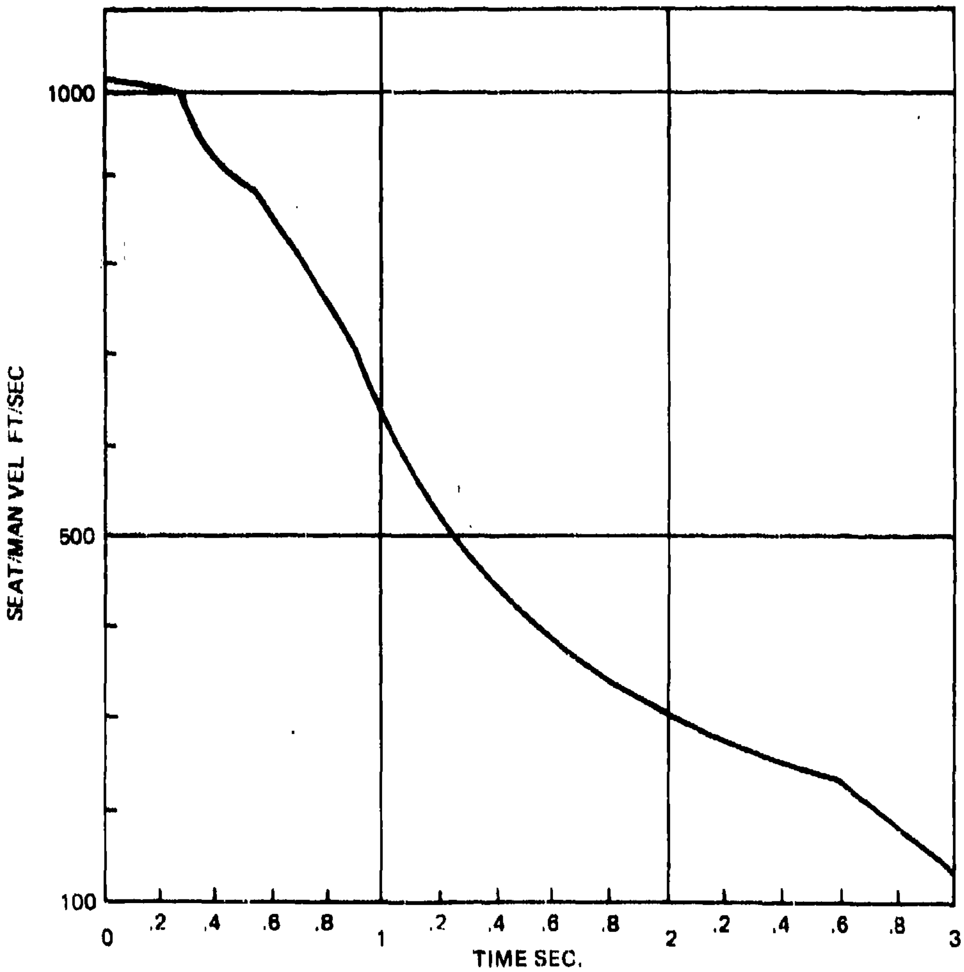


Figure 53 Computer Run – 600 KTS, S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 5 of 6)

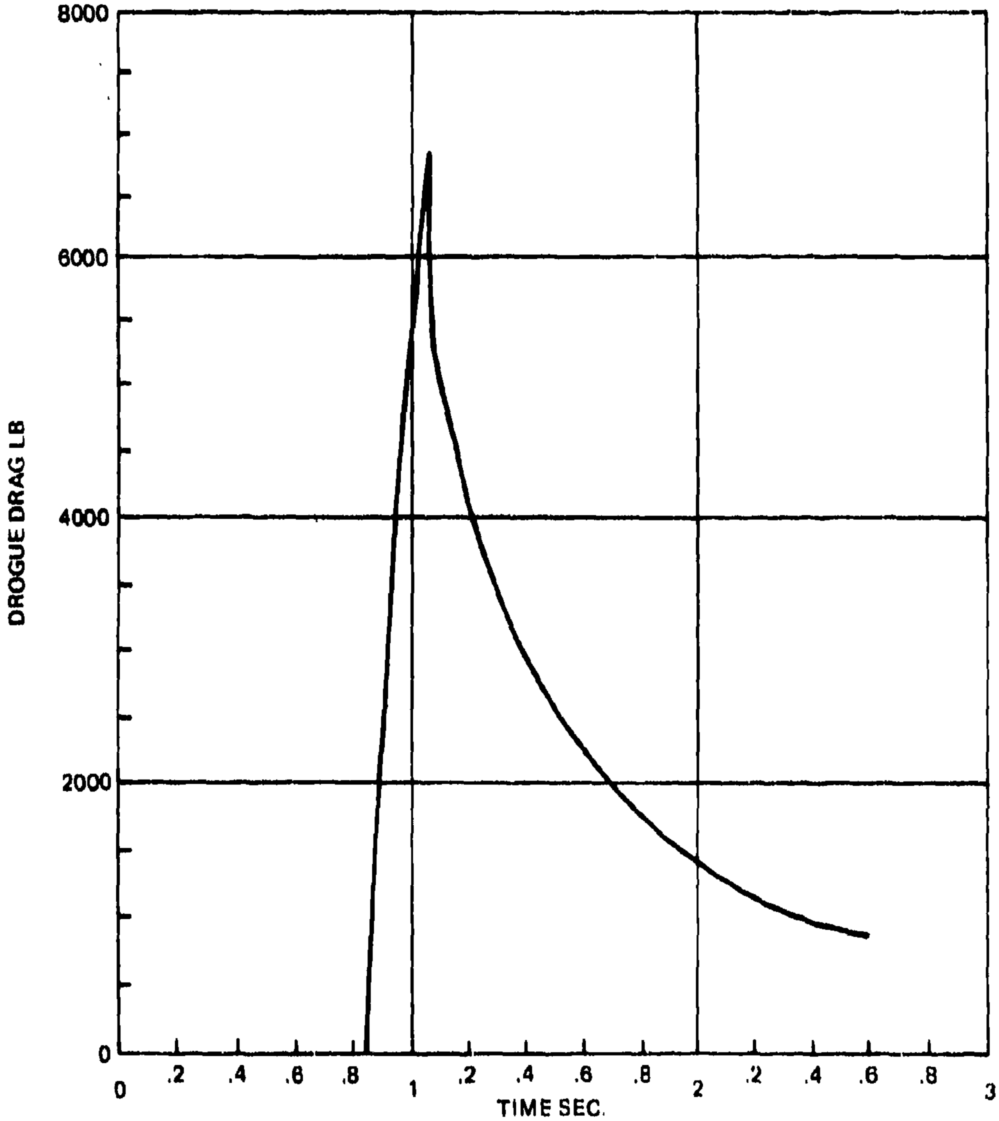


Figure 53 Computer Run – 600 KTS. S.L. MK-GRU7 Type Seat Configuration 7 (Sheet 6 of 6)

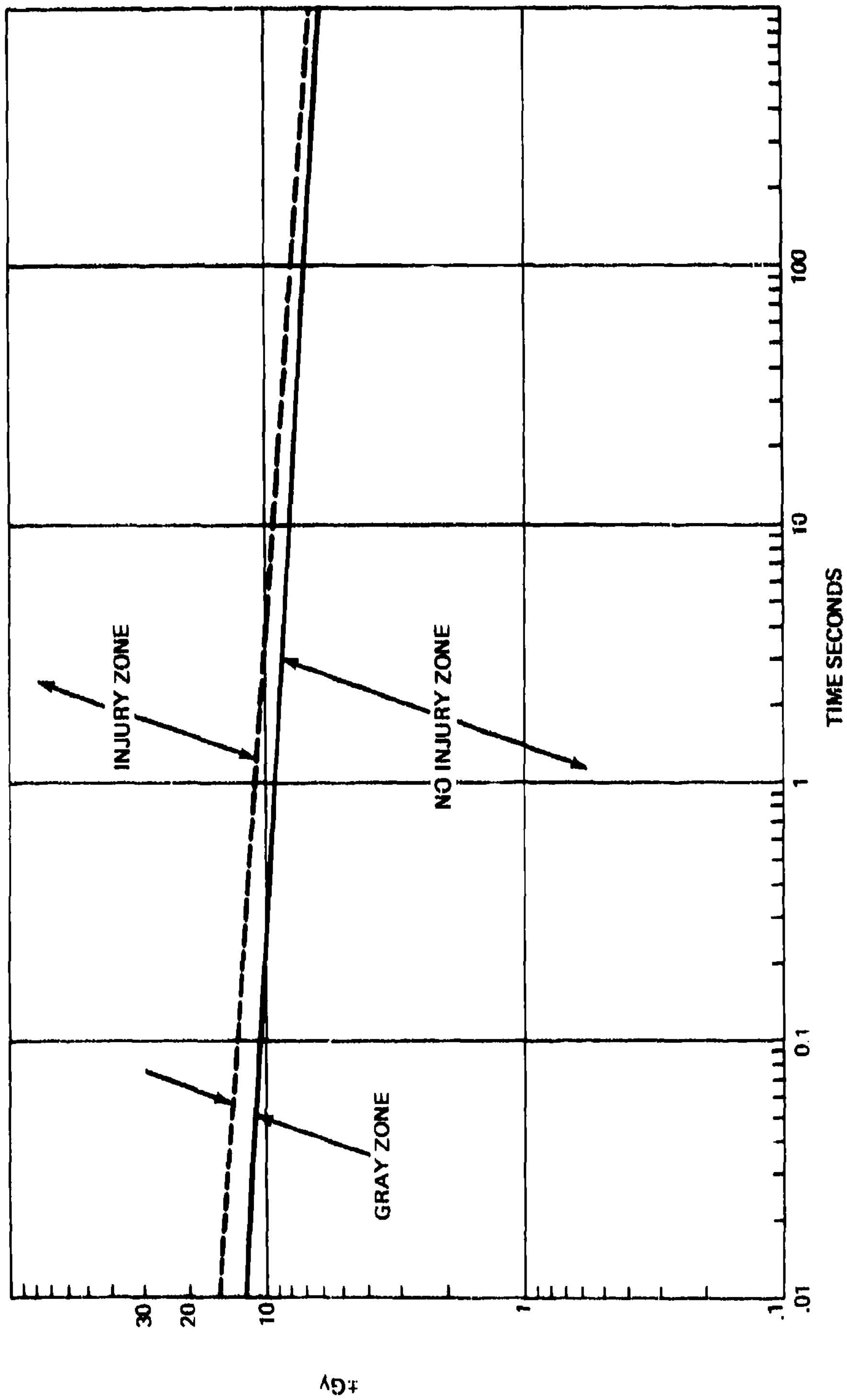


Figure 54 Lateral Gee Human Tolerance

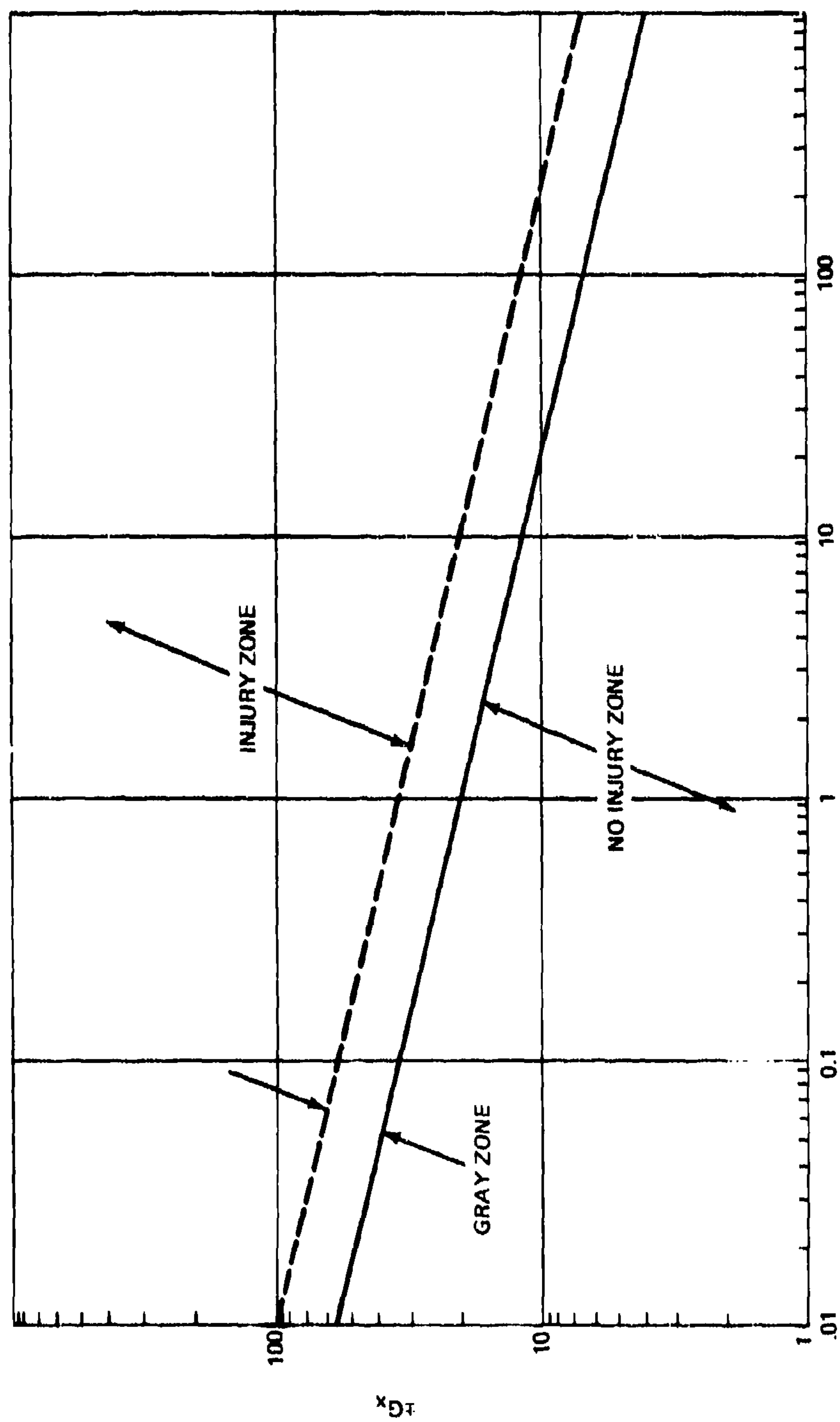


Figure 55 Transverse Gee Human Tolerance

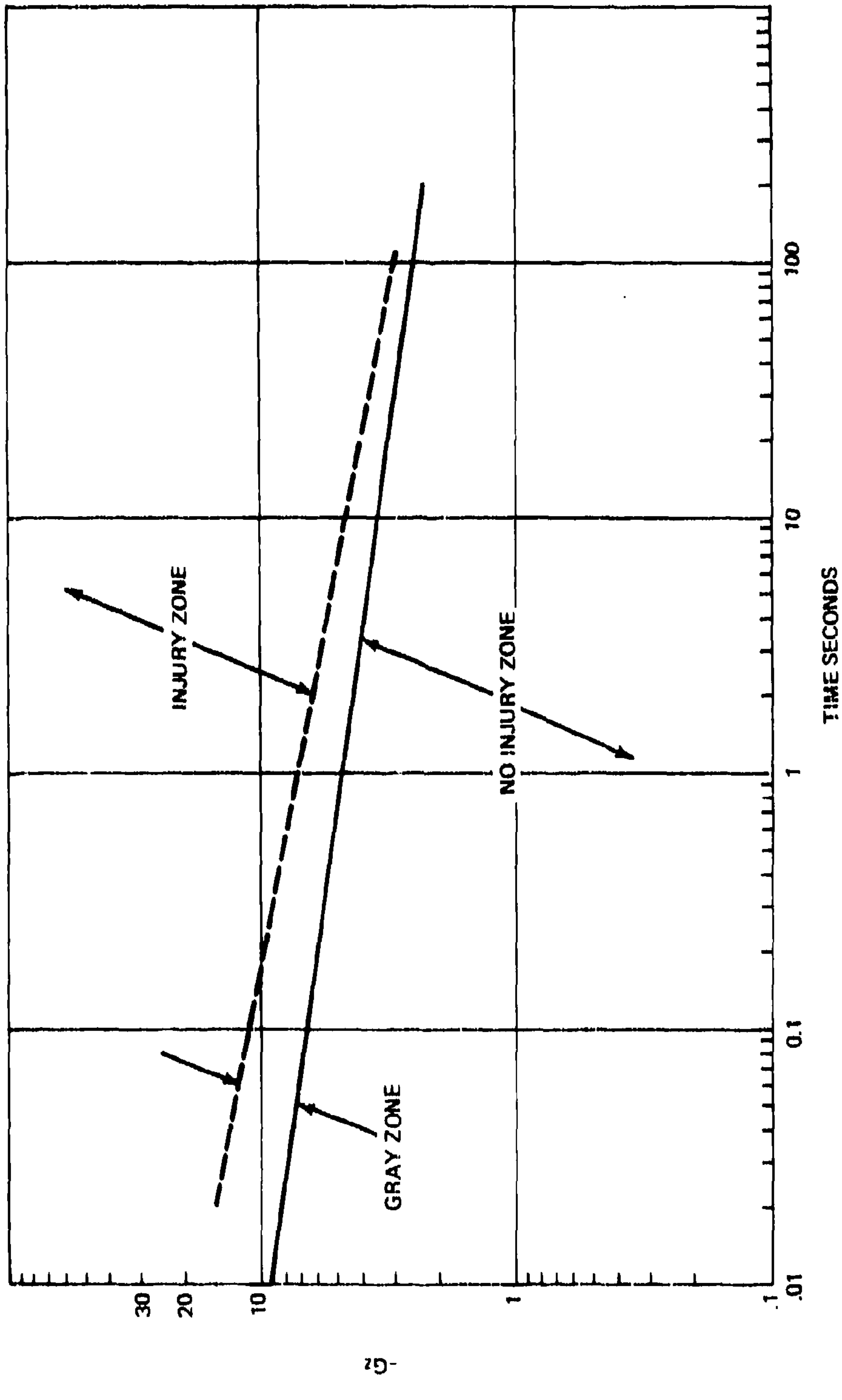


Figure 56 Negative Vertical Gee Human Tolerance

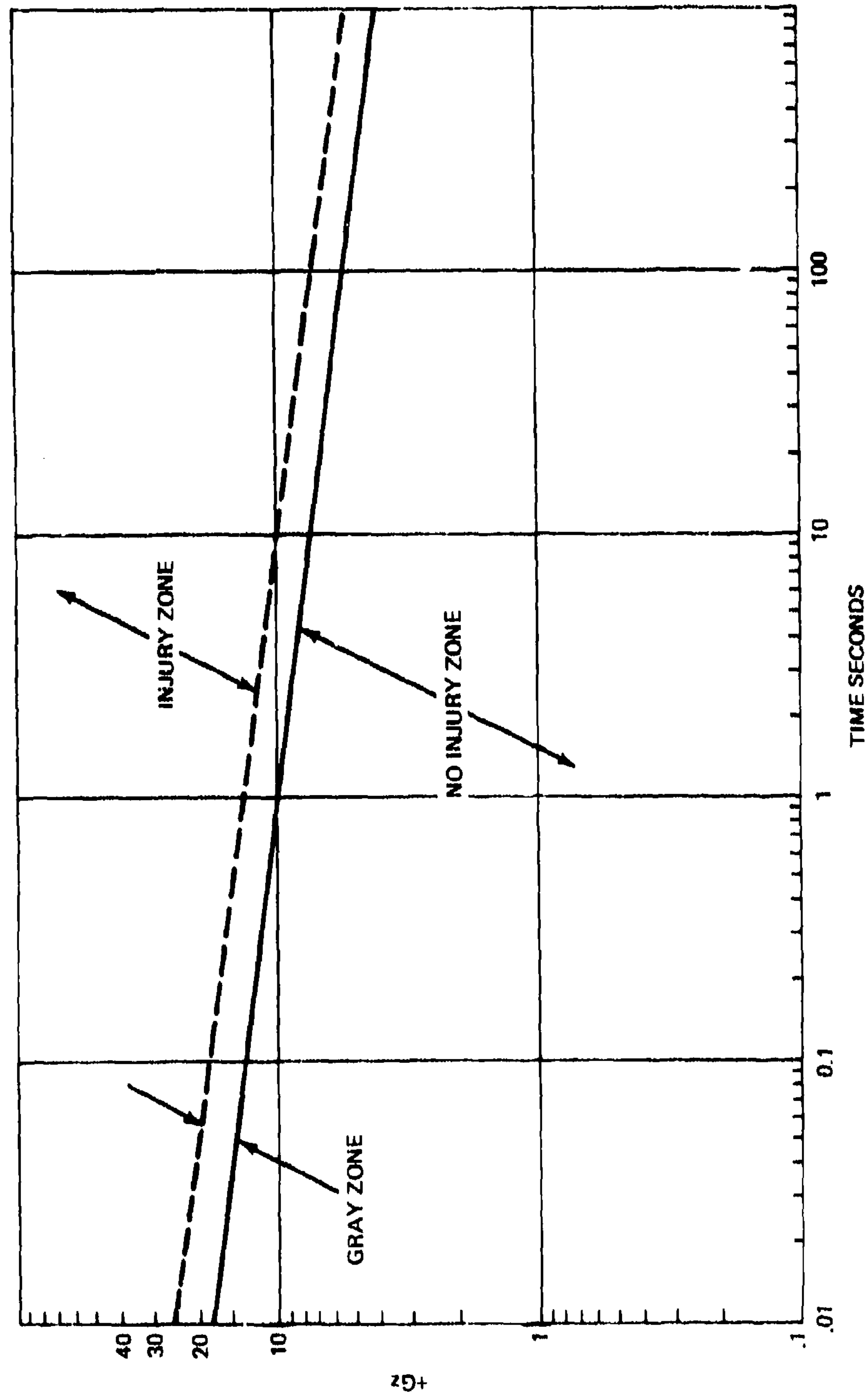


Figure 57 Positive Vertical Gee Human Tolerance

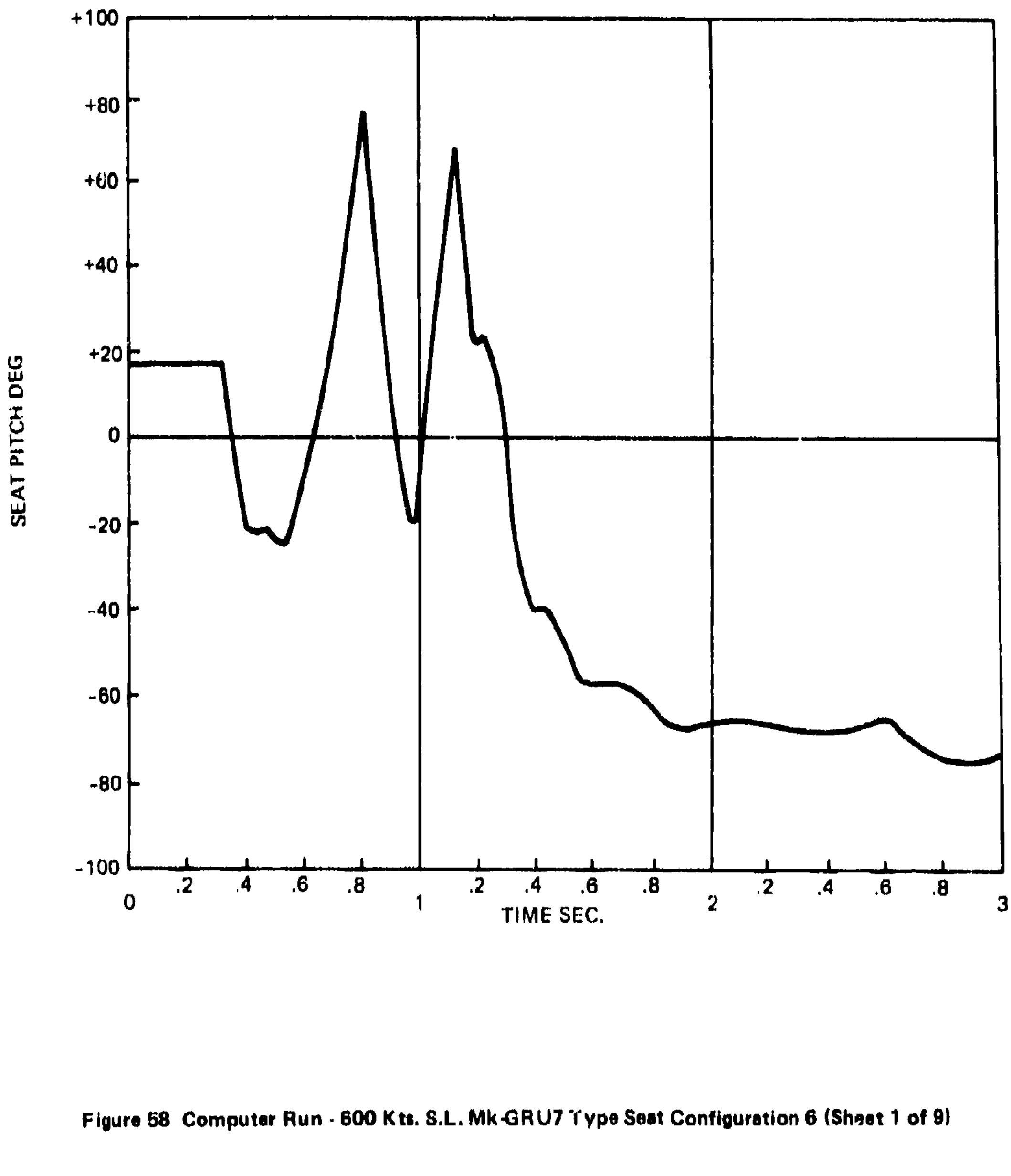


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 1 of 9)

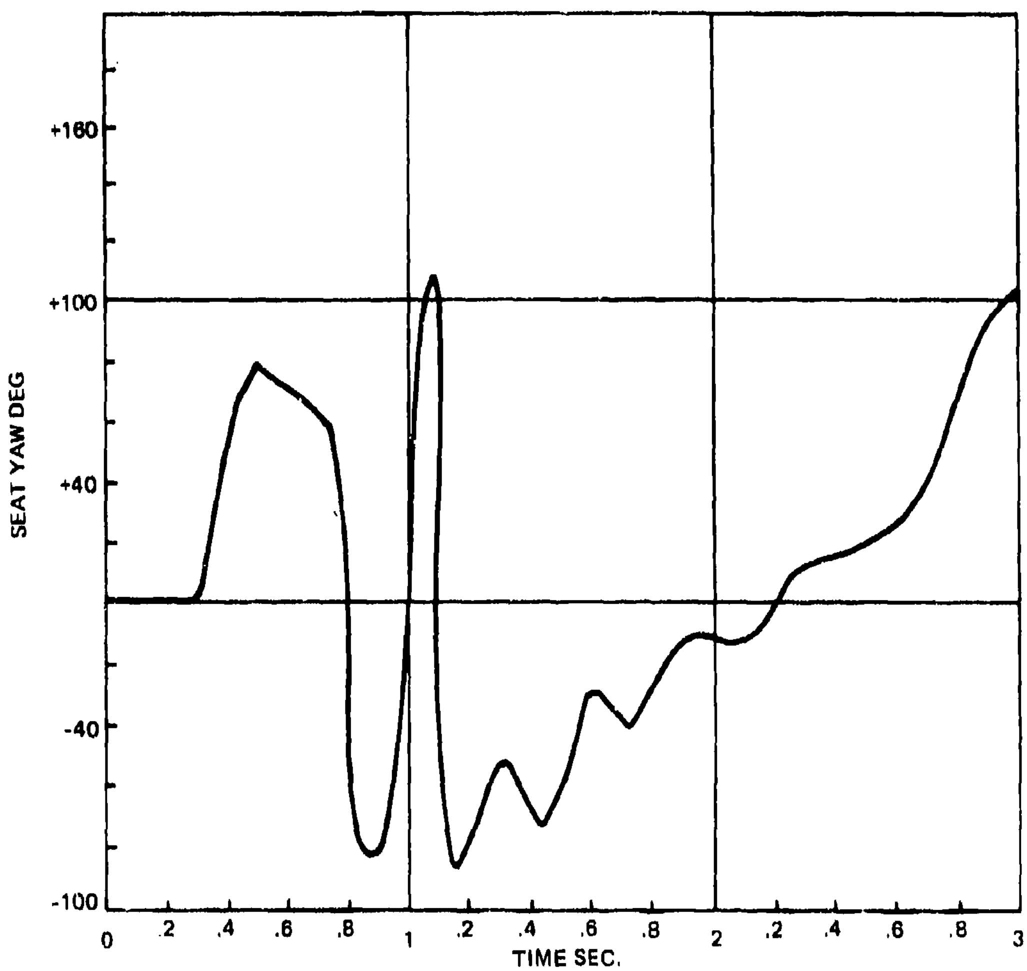


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 2 of 9)

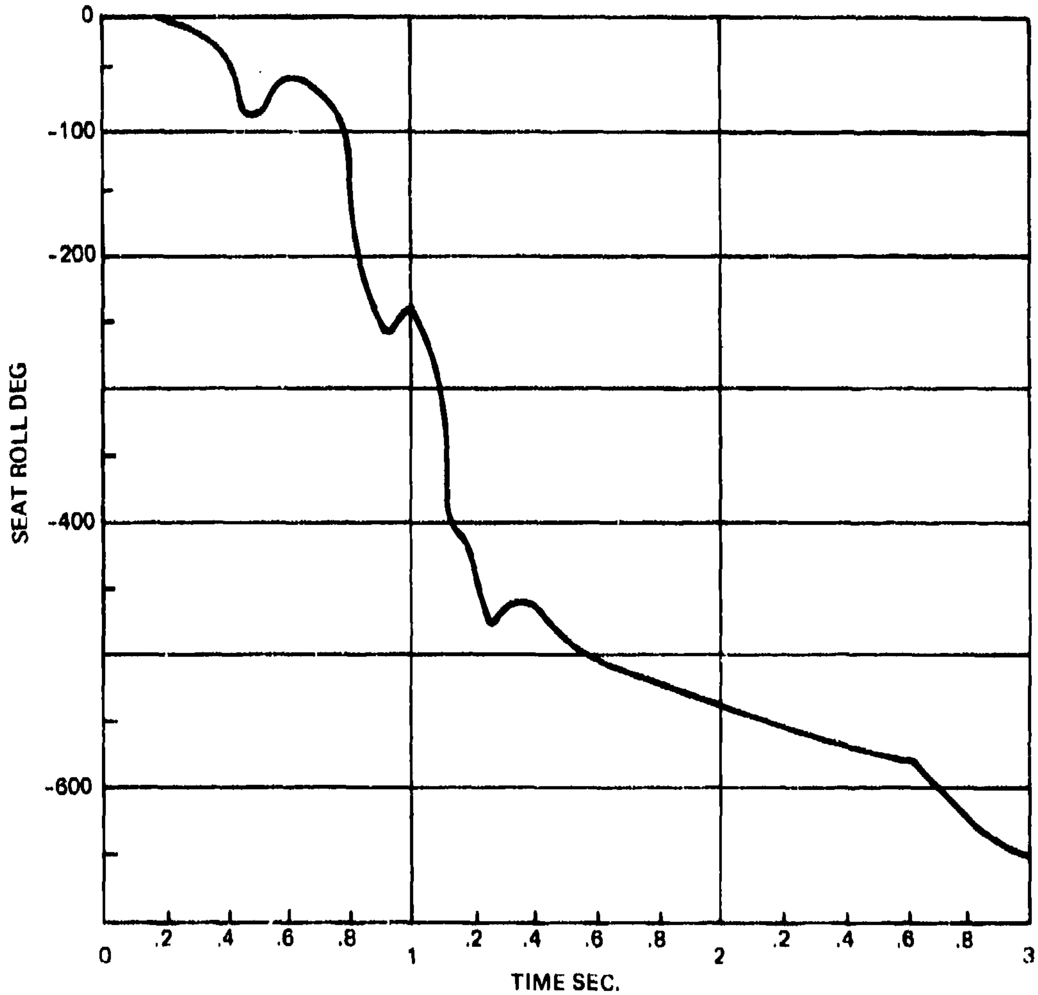


Figure 53 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 3 of 9)

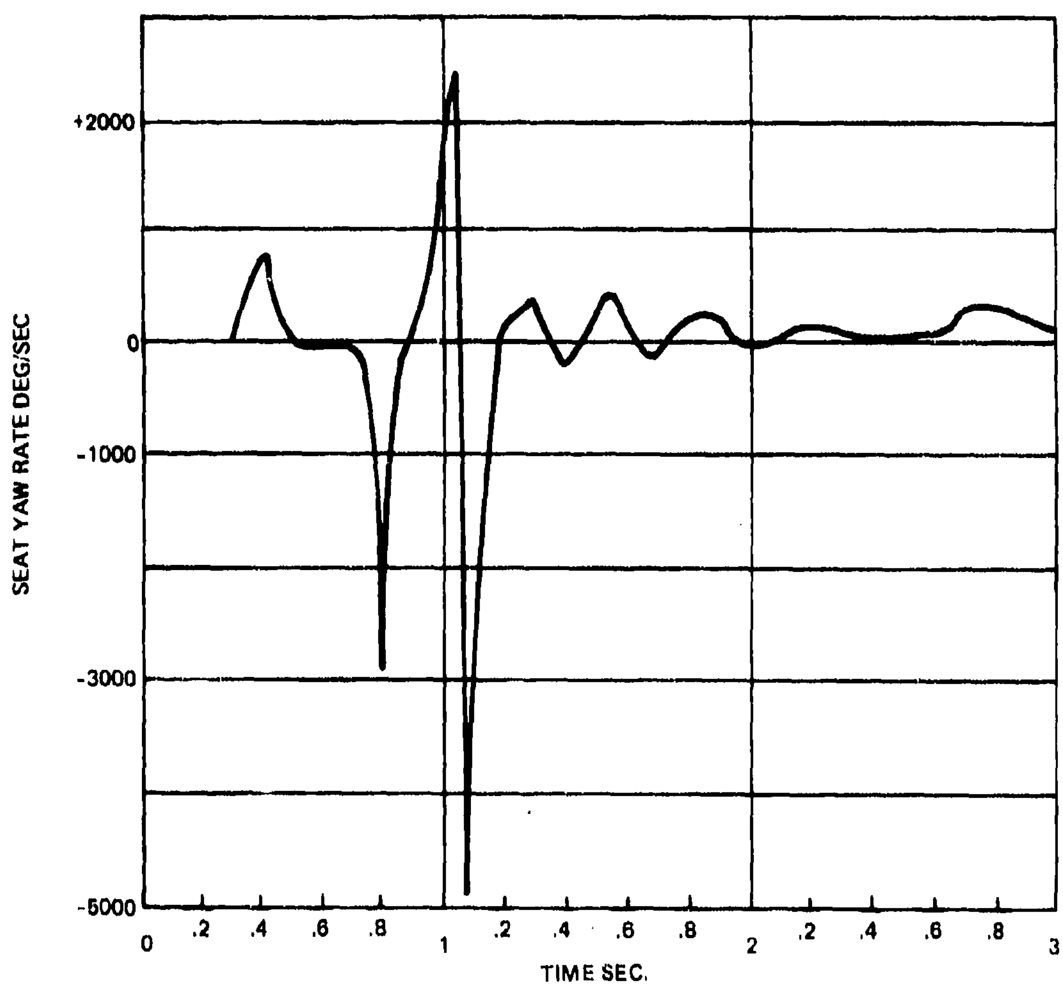


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 4 of 9)

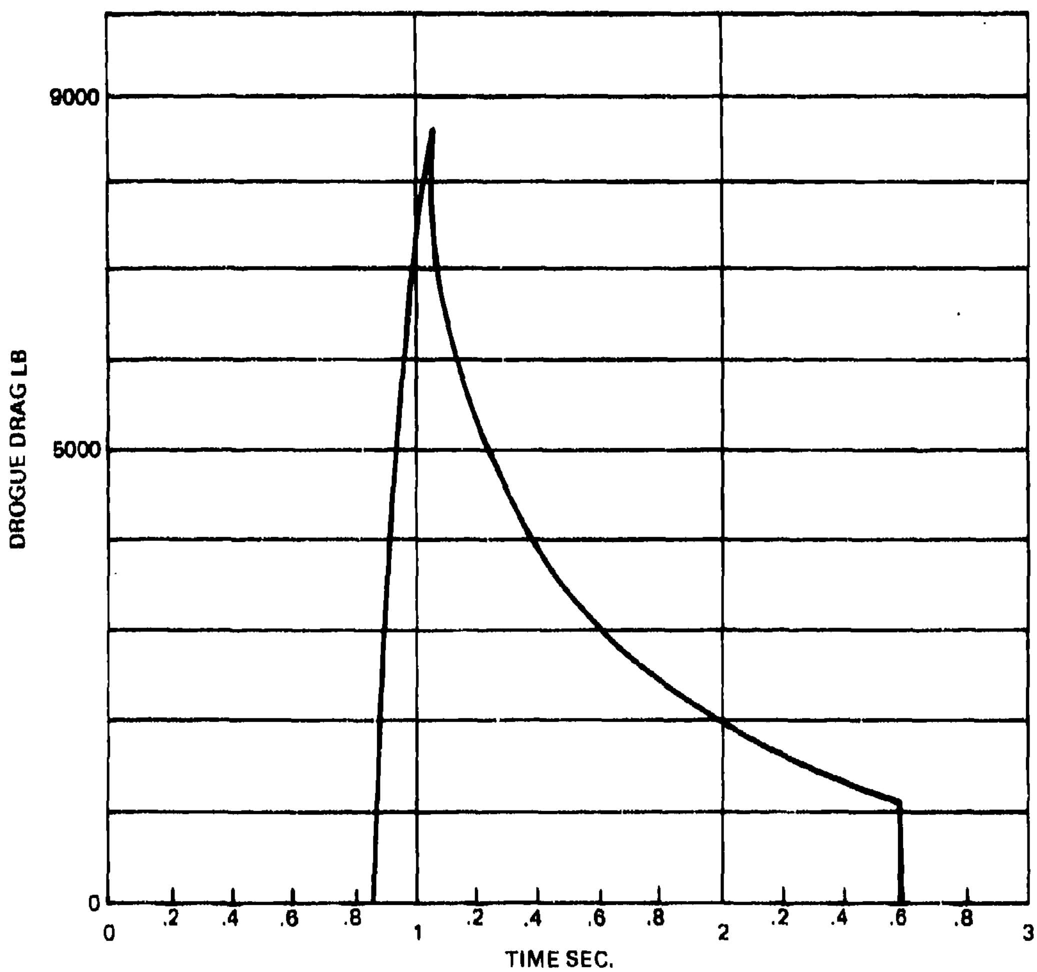


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 5 of 9)

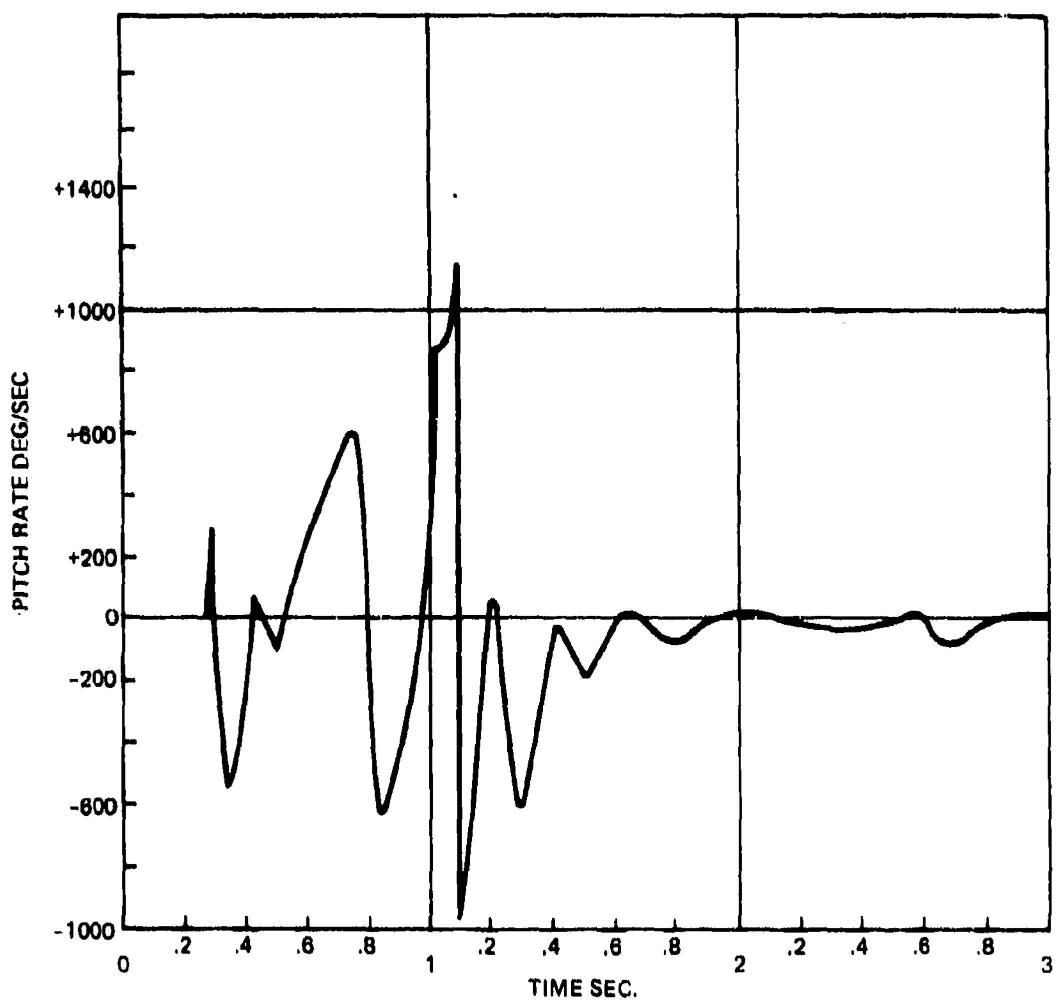


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 6 of 9)

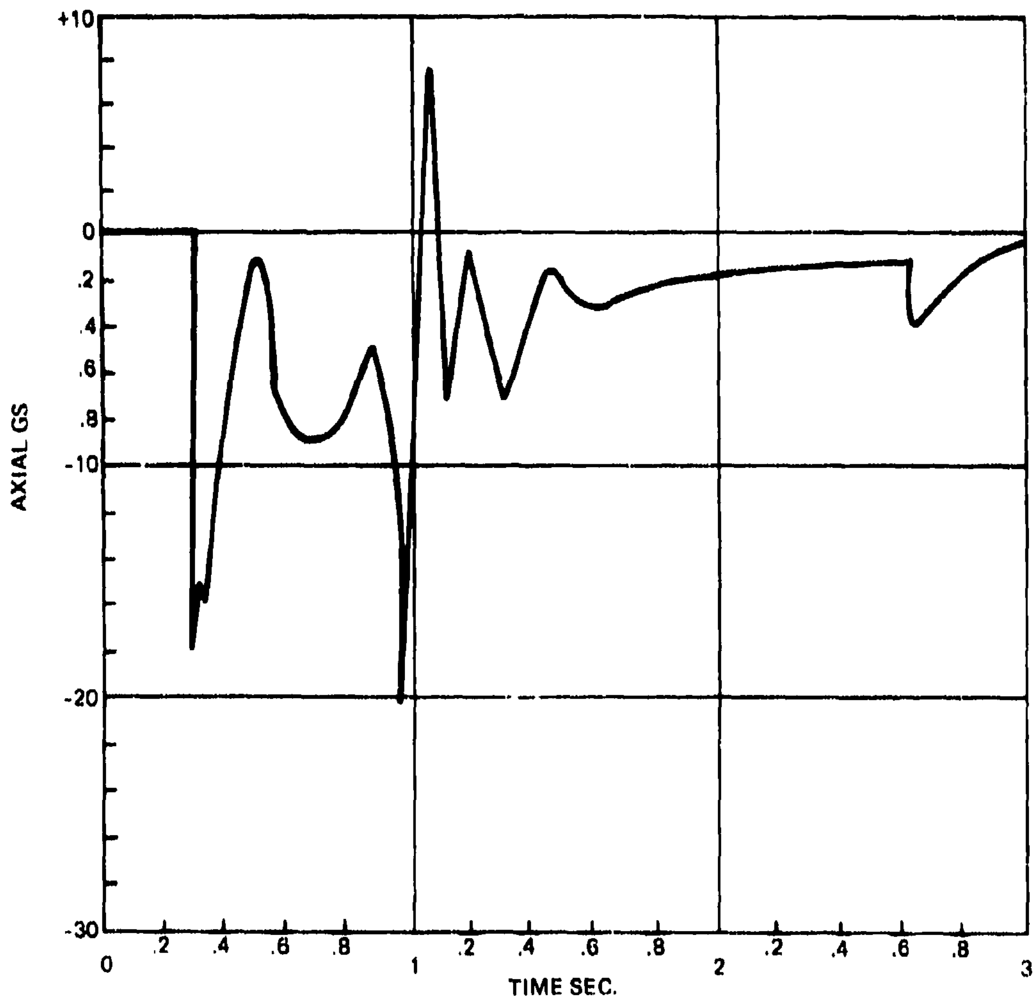


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 7 of 9)

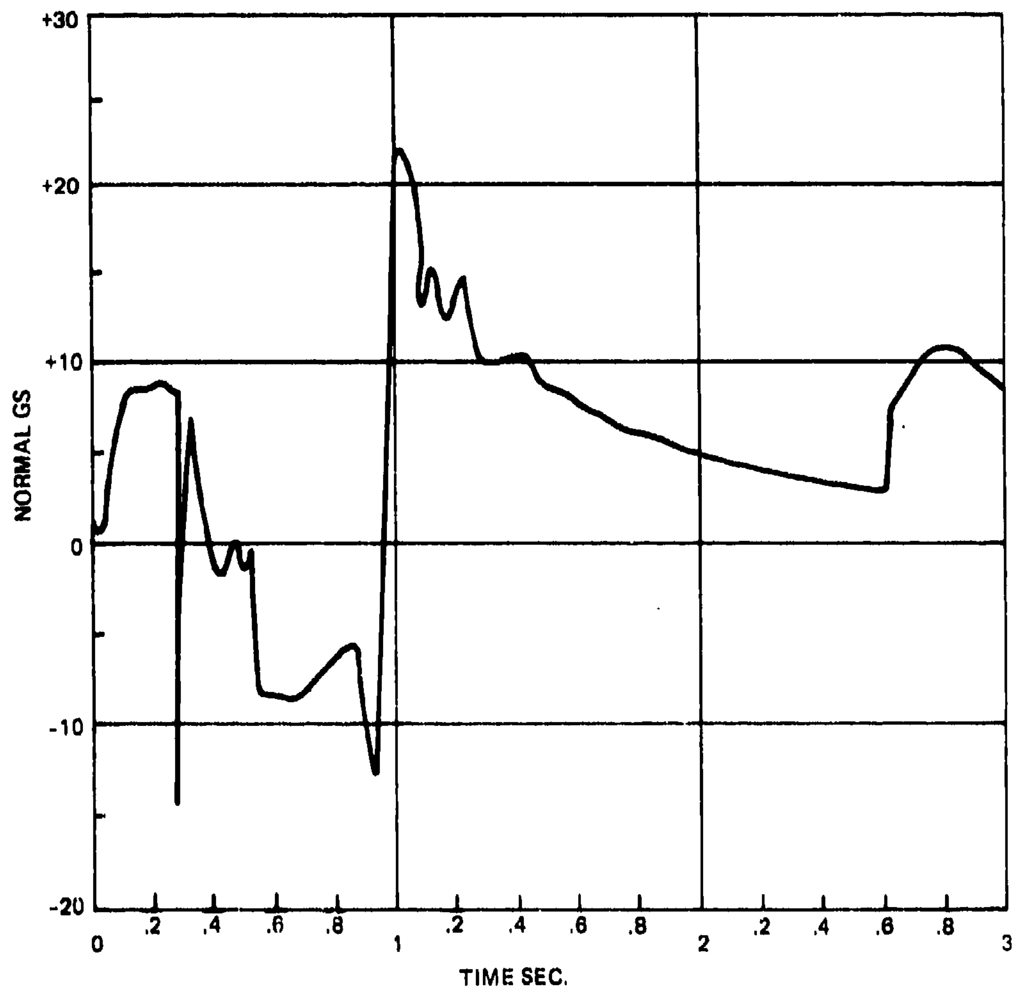


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 8 of 9)

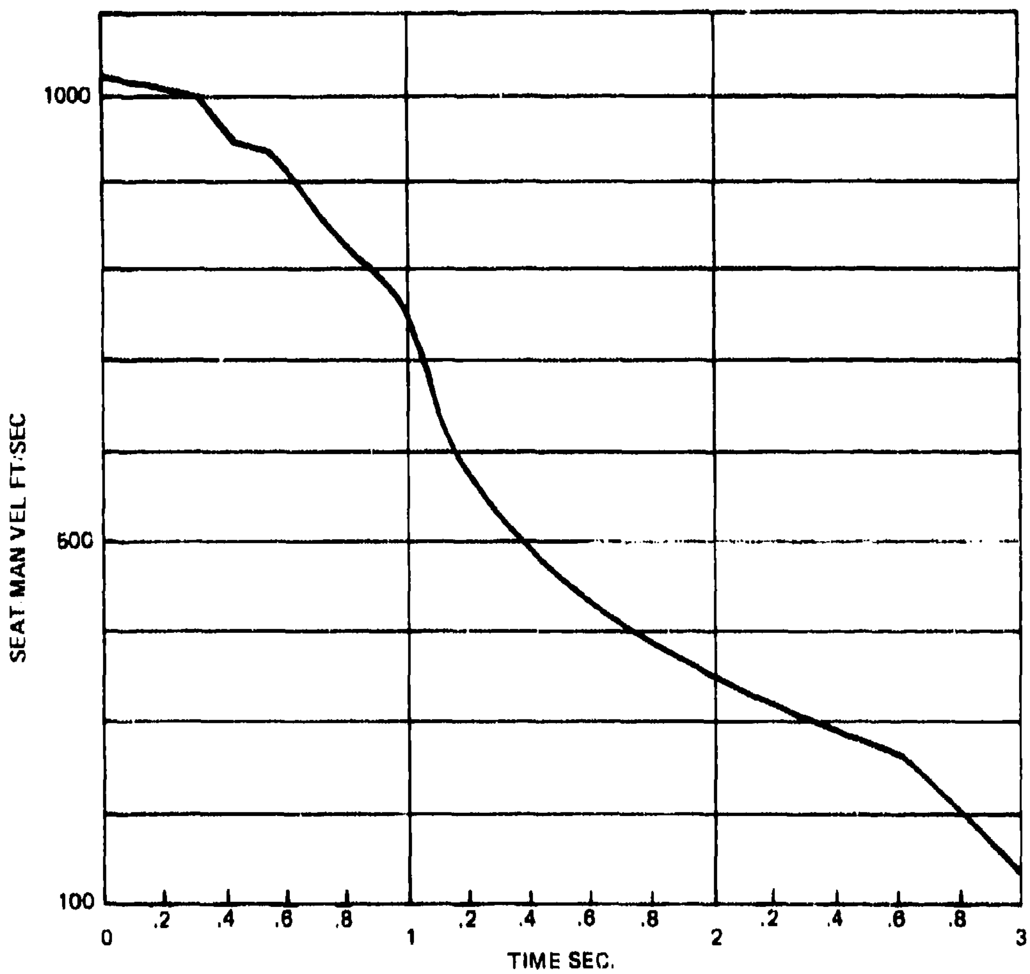


Figure 58 Computer Run - 600 Kts. S.L. Mk-GRU7 Type Seat Configuration 6 (Sheet 9 of 9)

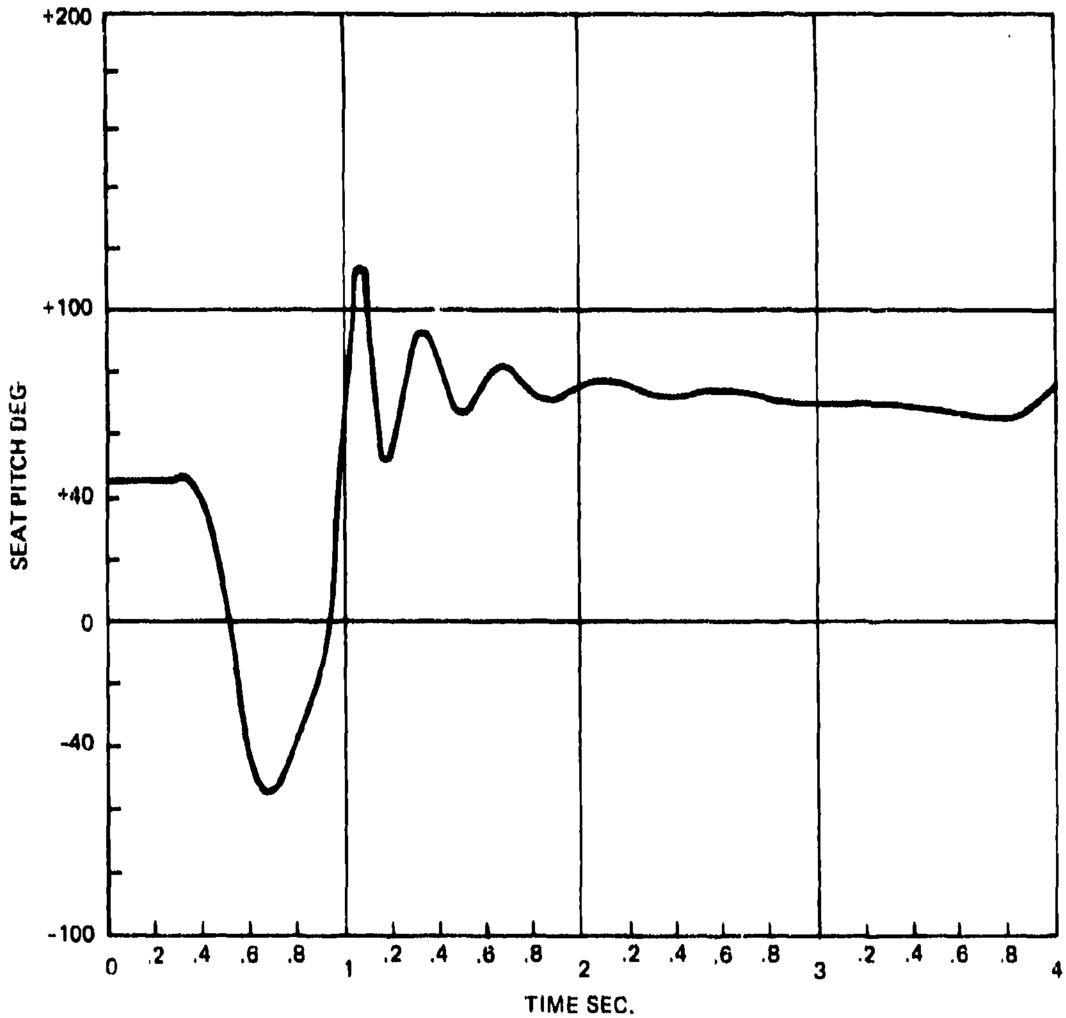


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 1 of 9)

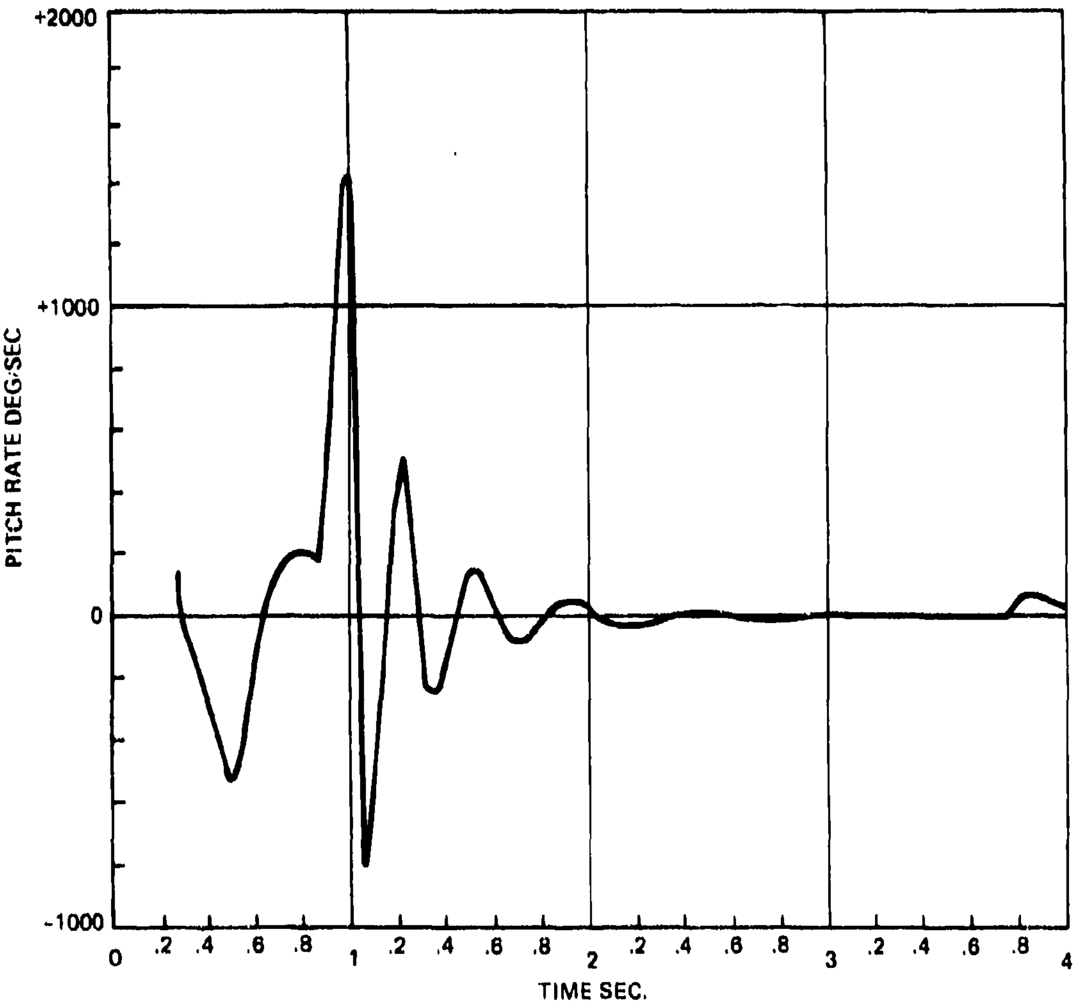


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 2 of 9)

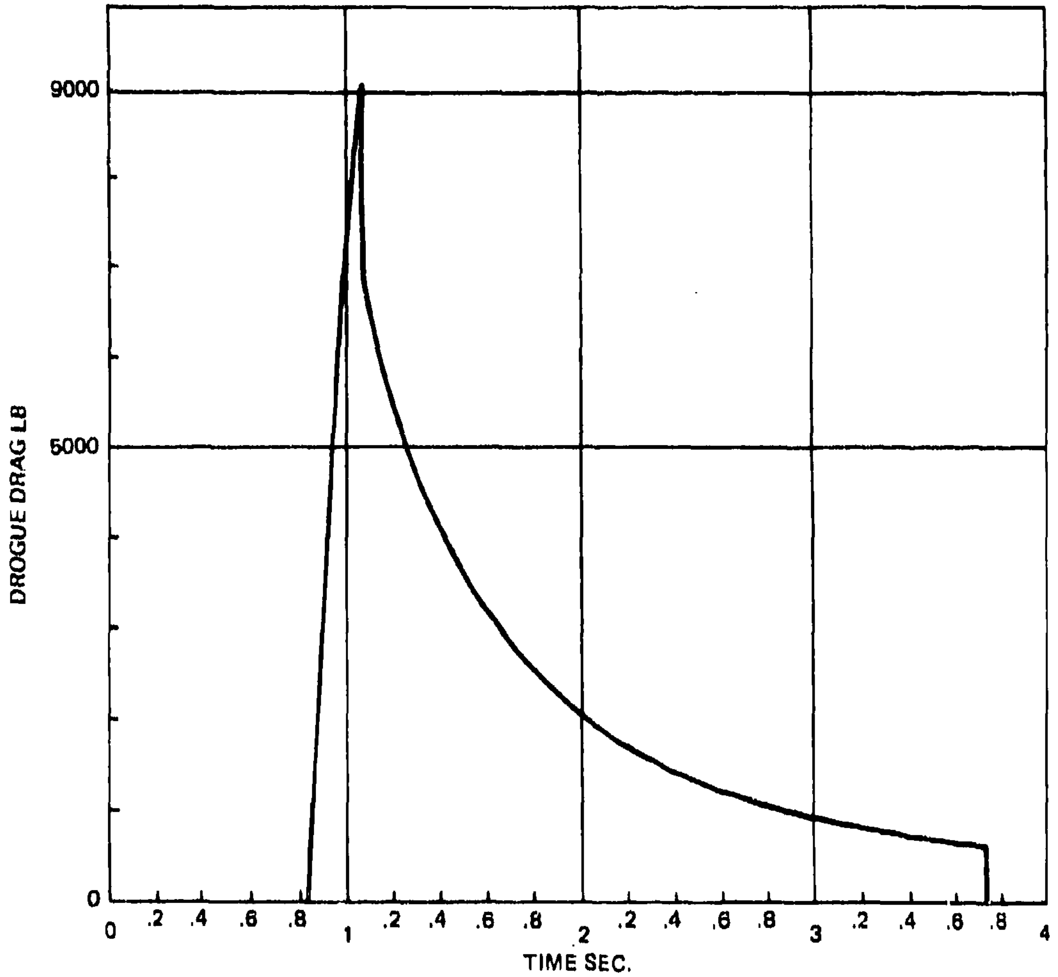


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 3 of 9)

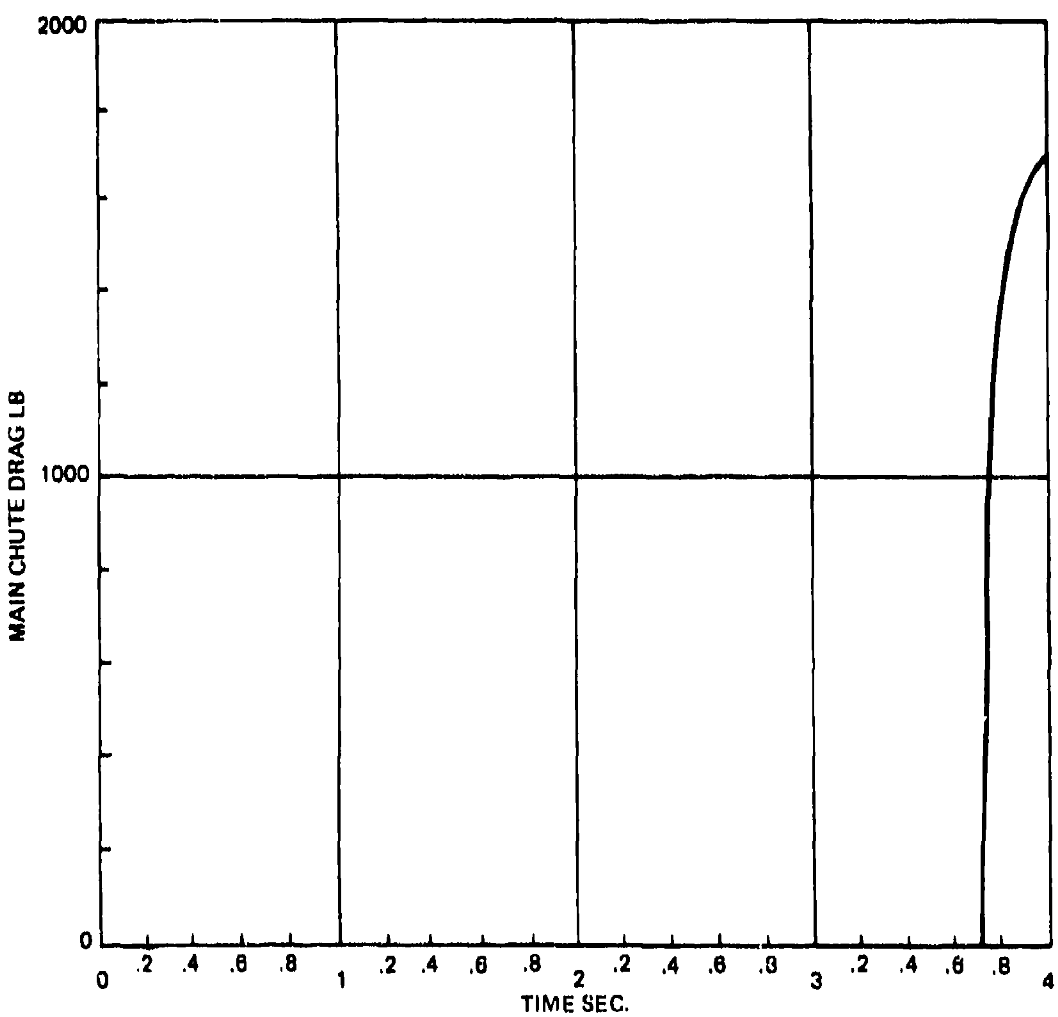


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 4 of 9)

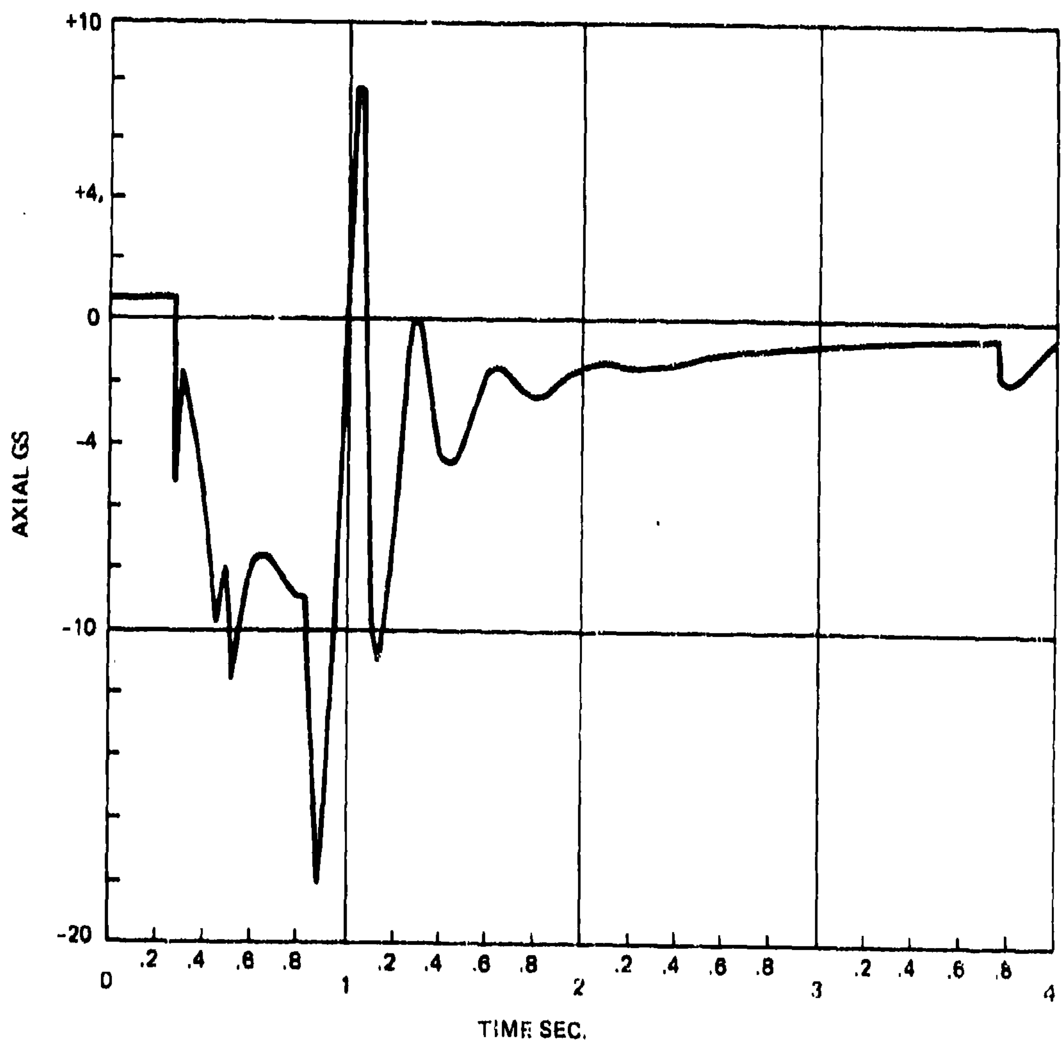


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 5 of 9)

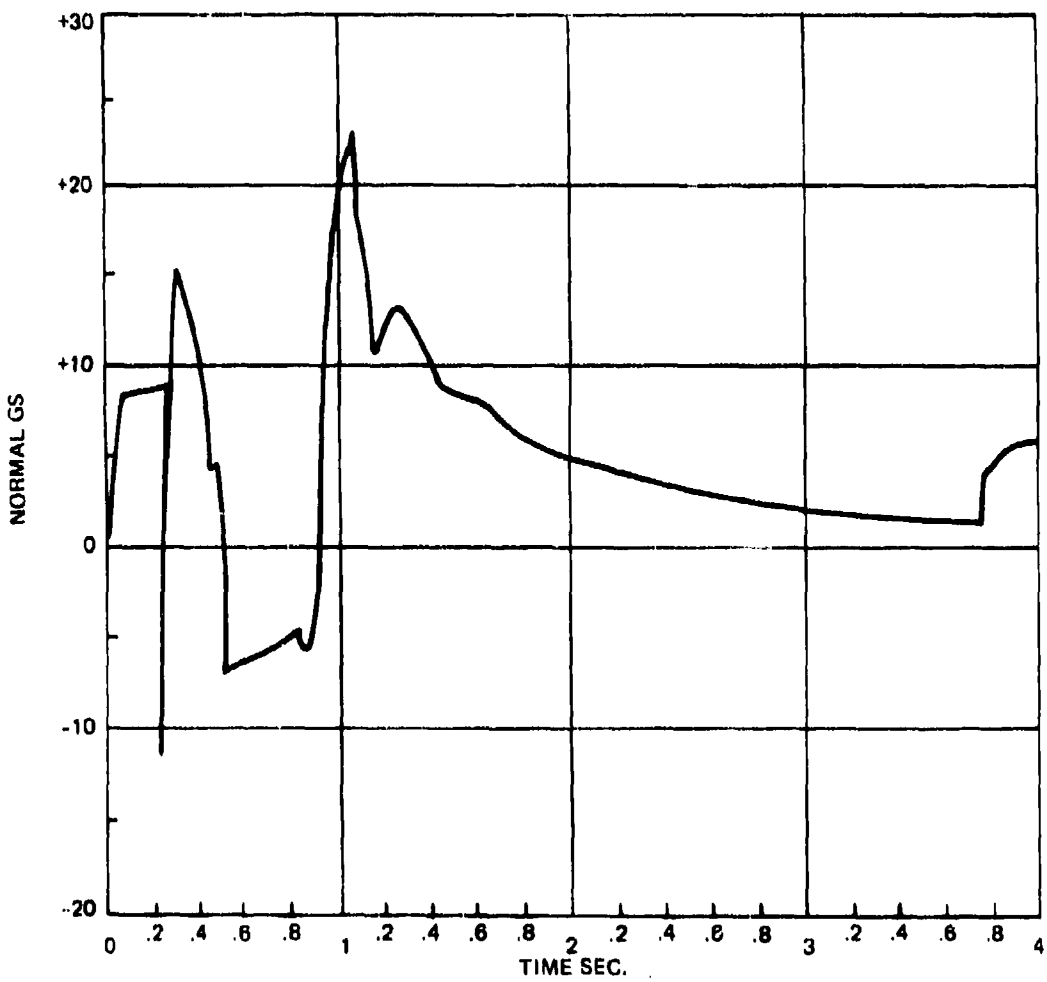


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 6 of 9)

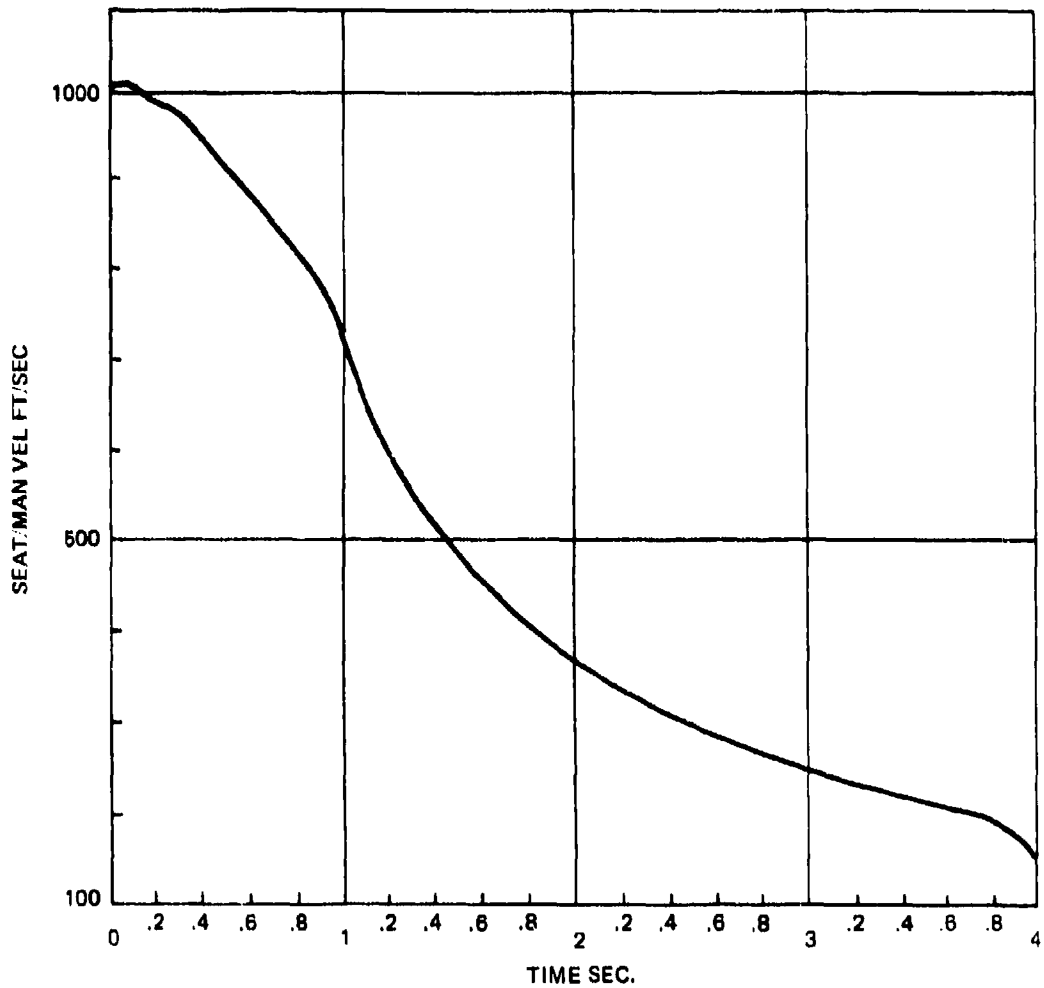


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 7 of 9)

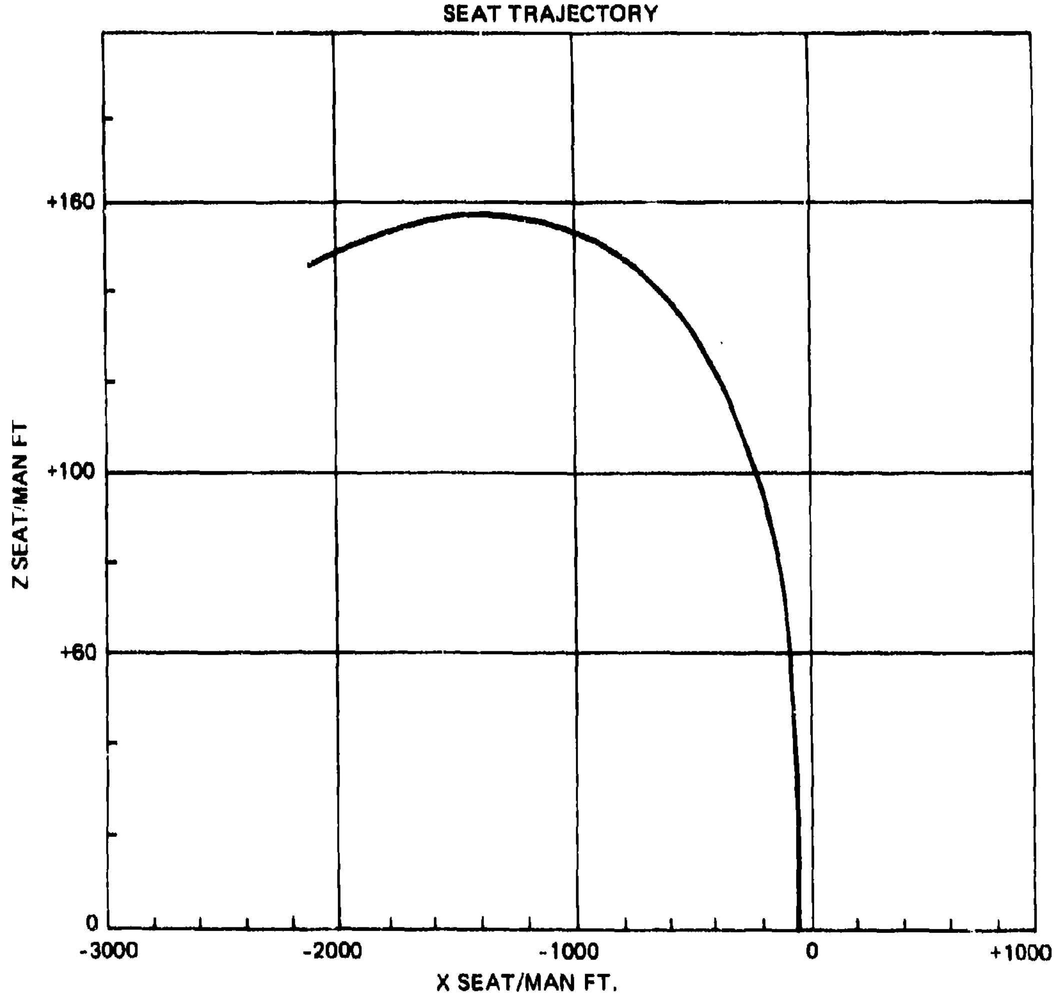


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 8 of 9)

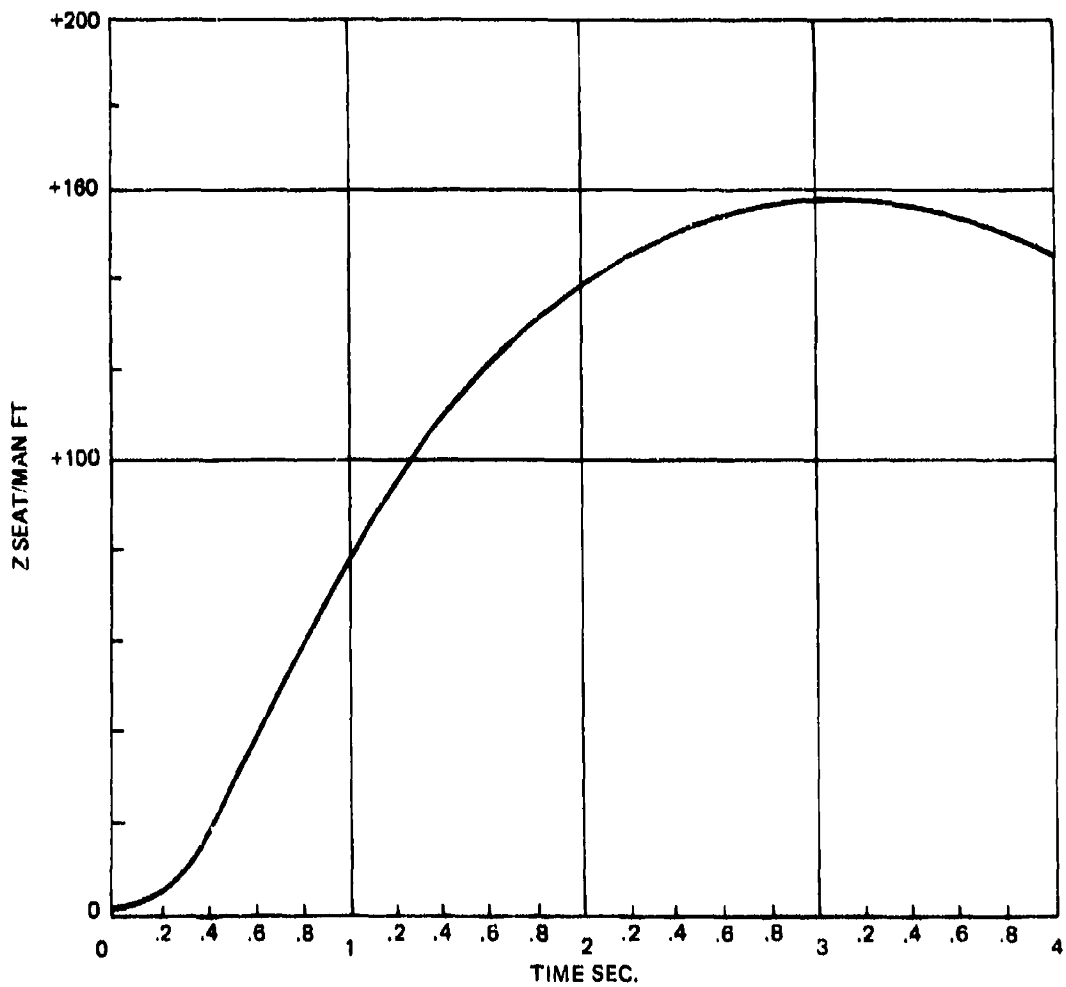


Figure 59 Computer Run - 600 KTS Sea Level MK-GRU7 Type Seat 45 Degree Ejection Angle (Sheet 9 of 9)

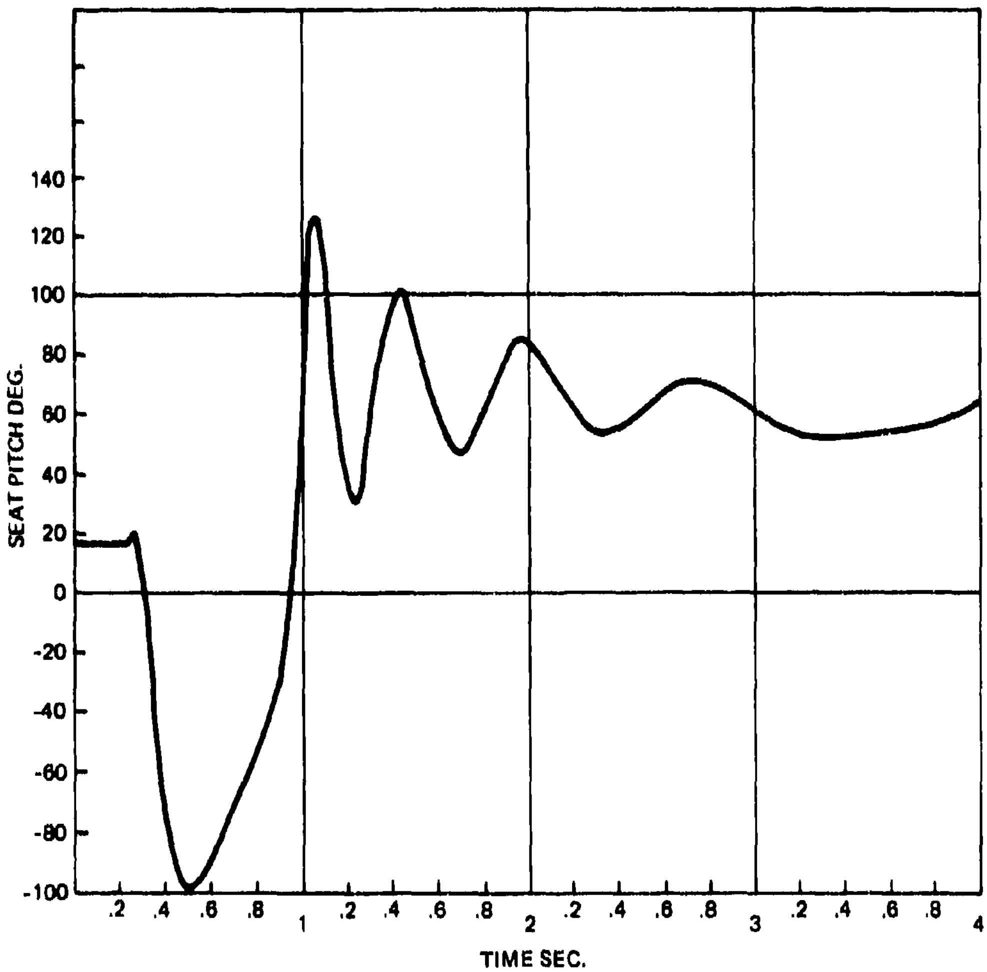


Figure 60 Computer Run – 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 1 of 6)

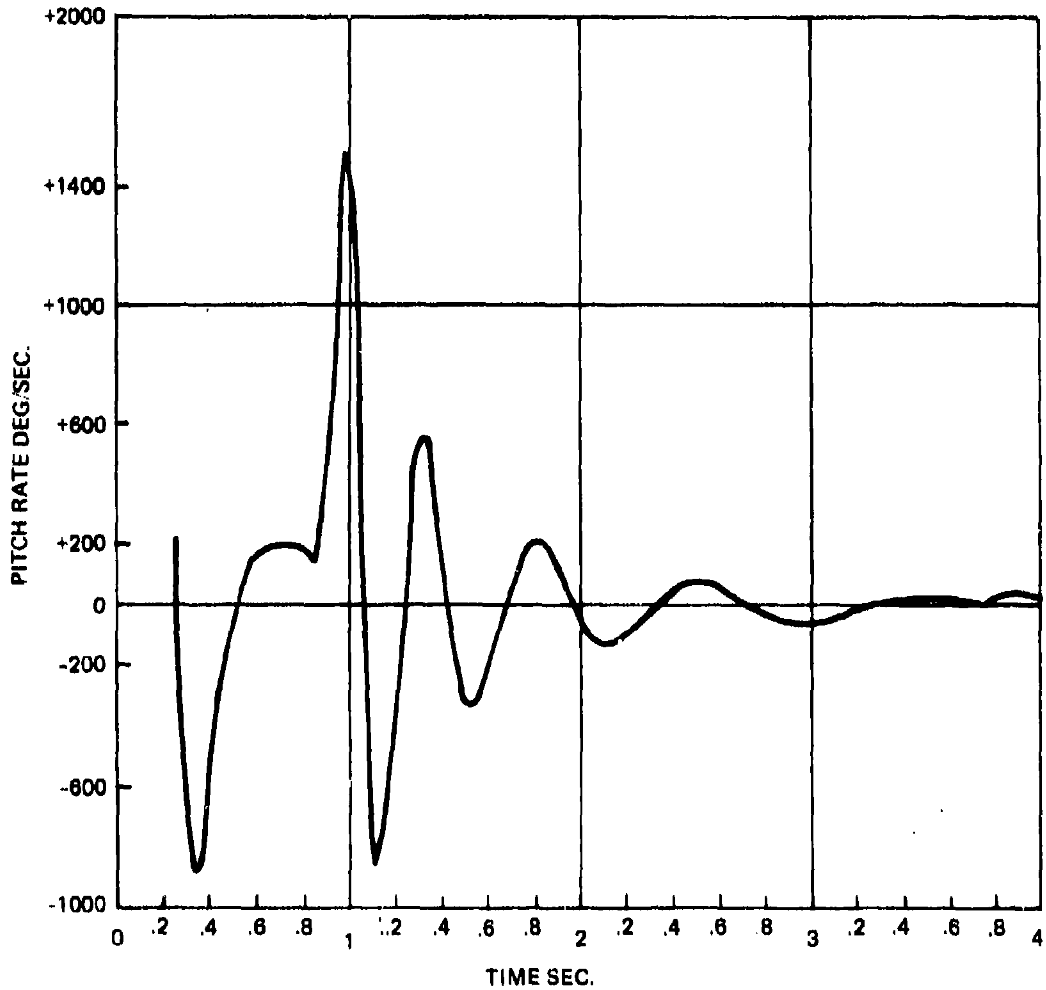


Figure 60 Computer Run – 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 2 of 6)

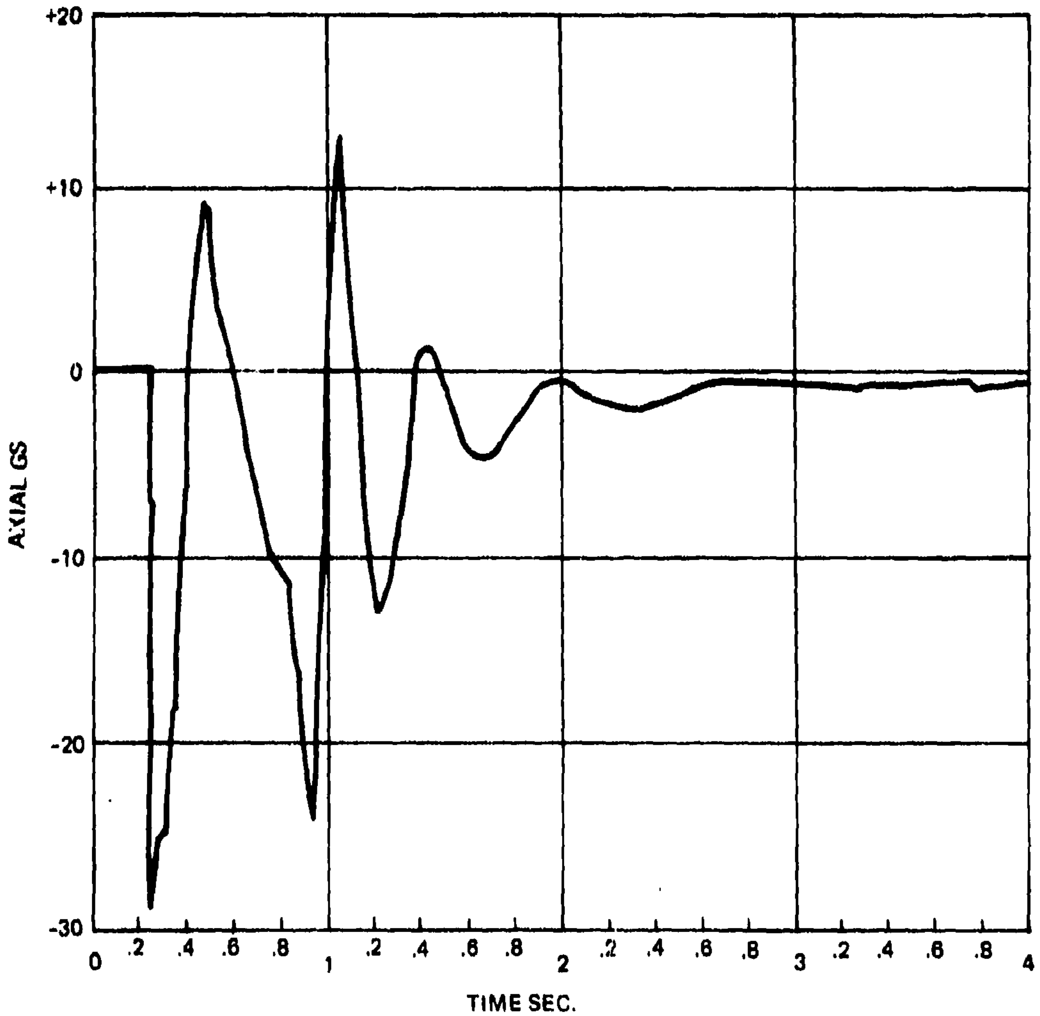


Figure 60 Computer Run — 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 3 of 6)

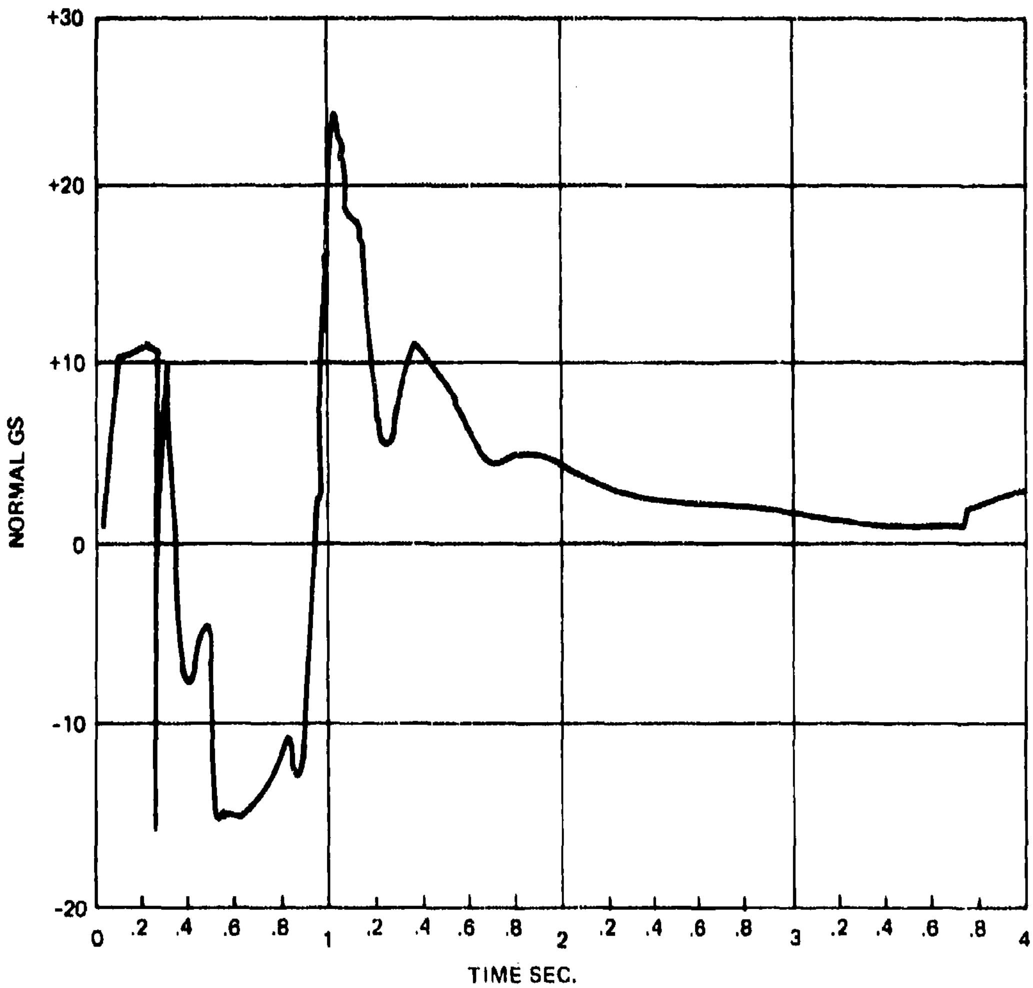


Figure 60 Computer Run – 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 4 of 6)

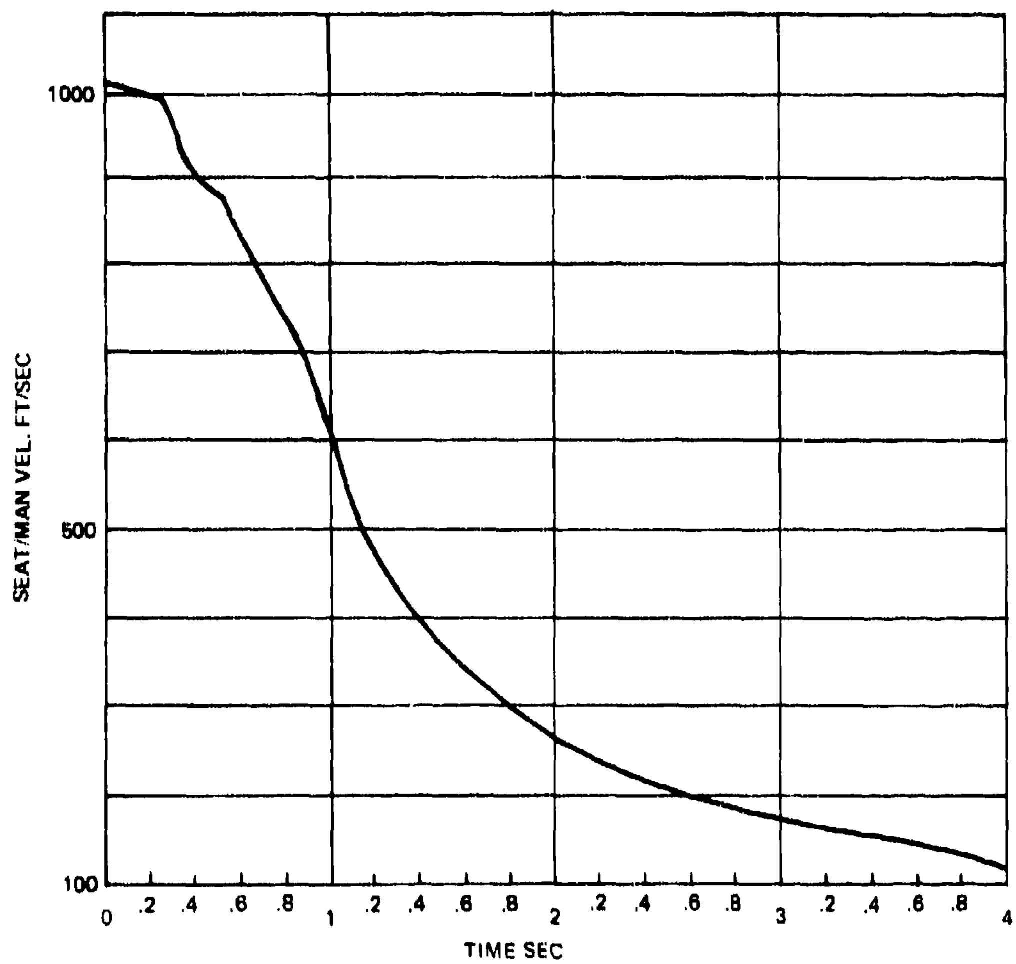


Figure 60 Computer Run – 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 5 of 6)

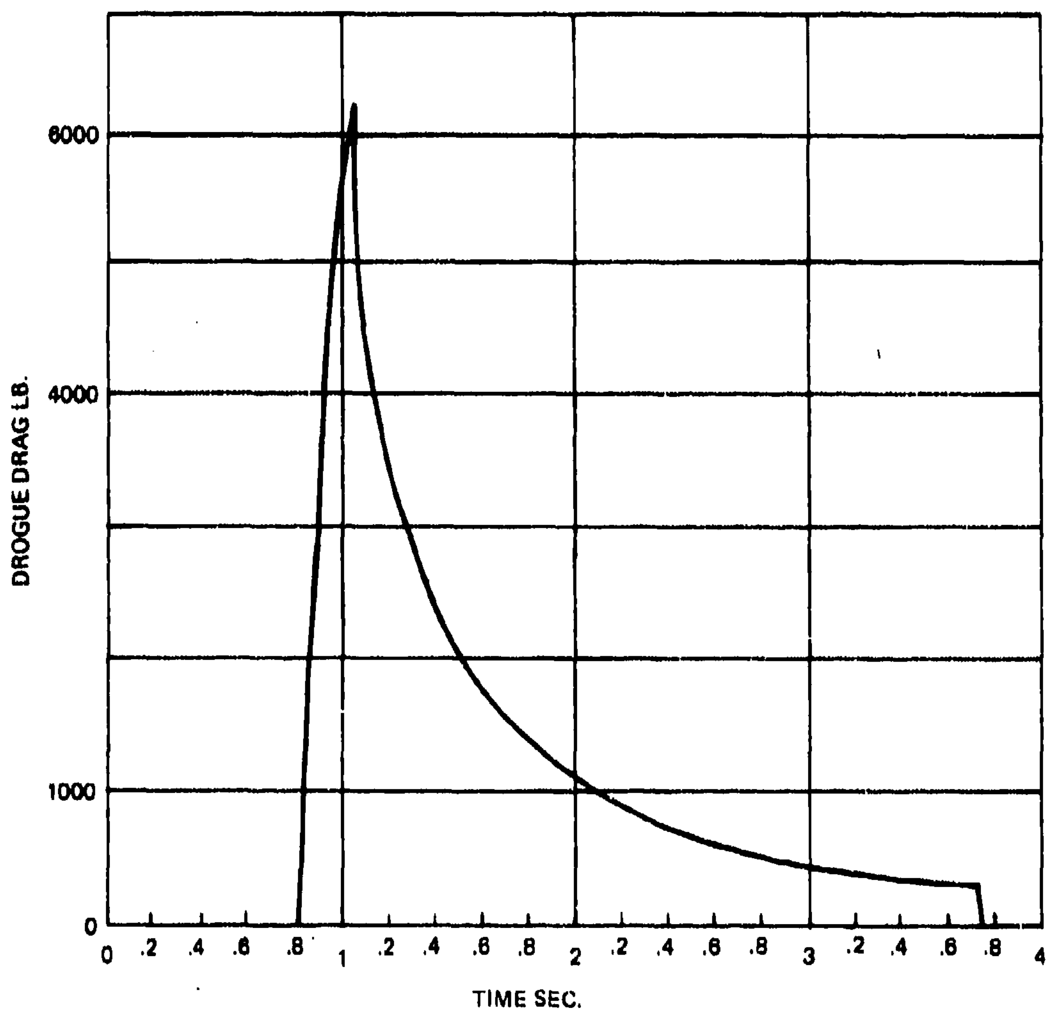
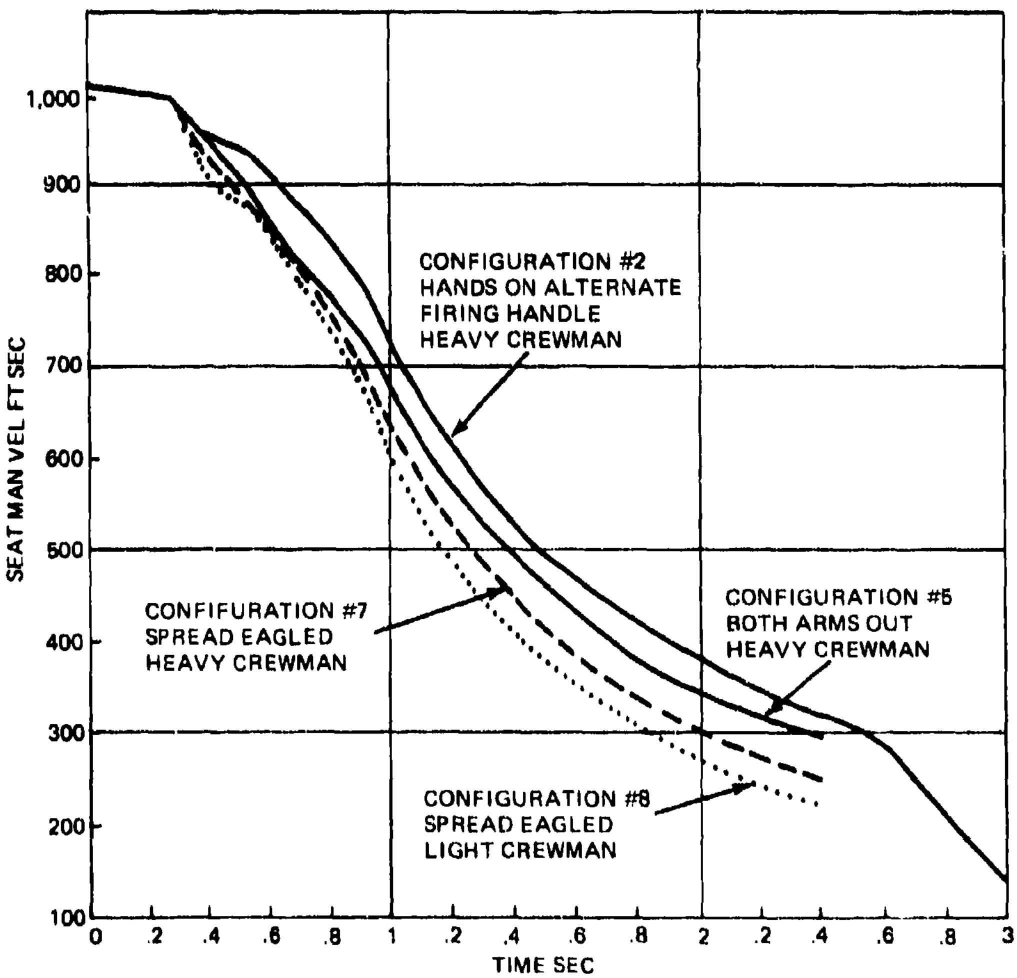


Figure 60 Computer Run – 600 Kts. S.L. MK-Gru 7 Type Seat Configuration 8 (Sheet 6 of 6)



NOTE: VELOCITY DATA TAKEN FROM FIGURES 47, 52, 53, AND 60 FOR COMPARISON

Figure 61 Computer Run – 600 KTS S.L. MK-GRU7 Type Seat Seat/Man Velocity Comparison for Configurations 2, 5, 7 & 8

System Category		Conditions/Constraints: Ejection Forces	Windblast Forces	Deceleration Forces	Thermal	Retention: Head	Legs	Arms	Torso	Retention Initiation: Automatic Initiation	Retention Release: Automatic by Ejection Initiation	Automatic by System Programing	Manual for Non Eject Emergency	Life Sciences: Anthropometry Compatibility	Dynamic Displacement Effects	Body Position Relative to Forces	Body Position Relative to Comfort	Body Position Relative to Task Capabilities	Crewman Acceptance	Compatibility to: Existing Personnel & Survival Equipment	Existing Escape Seat Systems	High Acceleration Cockpit	Underwater Escape	Command Sequence Ejection	Next Generation Personnel & Survival Equipment	Next Generation Escape Systems	Weight	Reliability	Maintenance	Acceptance Tabulation: Acceptable	Fair	Not Acceptable	Not Applicable	Systems for Consideration
Methods	FLEXIBLE RETENTION	A	A	A	A	N	A	A	A	A	A	A	A	A	A	O	O	O	A	F	A	A	A	A	A	A	A	A	A	23	1	1	3	X
	FOAM IN PLACE	A	N	N	A	A	O	N	F	A	N	O	O	F	A	O	O	O	A	F	A	A	F	N	A	A	F	A	F	11	6	5	6	
	INFLATABLES	A	F	F	A	A	O	N	F	A	O	O	O	F	A	O	O	O	A	F	A	A	A	N	A	A	A	A	F	13	6	2	7	X
	ENCAPSULATED SEATS	A	A	F	A	N	N	N	A	A	A	A	A	A	A	A	O	O	F	F	O	N	A	F	O	O	N	F	N	12	5	6	5	
	RIGID MECHANICAL RESTRAINT	F	F	F	A	N	A	N	O	A	A	O	O	N	N	O	O	O	N	F	F	F	F	N	F	F	N	A	A	6	9	7	6	
	CREWMAN GARMENTS	A	F	A	A	O	O	O	A	O	O	O	O	A	O	O	O	O	A	F	A	A	A	O	A	A	A	A	A	14	2	0	12	X
	FEOTAL POSITION	O	A	A	A	O	O	O	O	O	O	[illegible]	O	O	O	A	A	O	O	F	F	O	O	O	A	A	O	O	O	7	2	0	19	X
Techniques	EJECTION DIRECTION																																	
	45 DEGREES AFTWARD	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	A	A	A	F	F	A	O	O	O	O	F	A	A	7	3	0	18	X
	SEAT ORIENTATION STABILIZATION																																	
	AERODYNAMIC DEVICES																																	
	RIGID EXTENSIONS	O	O	F	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	F	A	O	O	O	A	F	A	A	5	7	1	15	
	DROGUE CHUTES	O	O	A	A	F	F	N	F	O	O	O	O	O	O	A	O	O	O	O	A	A	O	O	O	A	A	A	A	9	3	1	15	X
	AFTERBODY	O	O	A	A	F	F	N	F	O	O	O	O	O	O	A	O	O	O	O	F	A	O	O	O	A	F	A	F	6	6	1	15	X
	MECHANICAL DEVICES																																	
	DART	O	O	A	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	A	A	O	O	O	A	F	A	F	6	6	1	15	X
	EXTENDED GUIDE TRACKS	O	O	N	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	N	A	O	O	O	A	F	A	A	5	1	2	20	
	THRUSTING DEVICES																																	
	STAPAC	O	O	N	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	F	A	O	O	O	A	F	A	A	5	6	2	15	
	MULTIPLE FIXED THRUSTERS	O	O	F	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	F	A	O	O	O	A	F	F	F	3	9	1	15	
	TETHERED AFT FIRING ROCKETS	O	O	F	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	F	A	O	O	O	A	F	A	F	4	8	1	15	
	Q SENSING HEADREST ROCKET	O	O	F	A	F	F	N	F	O	O	O	O	O	O	F	O	O	O	O	F	A	O	O	O	A	F	A	F	4	8	1	15	
	THRUST VECTOR CONTROL ROCKET	O	O	A	A	A	A	N	A	O	O	O	O	O	O	A	O	O	O	O	F	A	O	O	O	A	F	A	A	10	2	1	15	X
	WIND DEFLECTOR/CANOPY SHIELDING																																	
	SKIP FLOW GENERATOR	O	N	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	N	N	O	O	O	N	N	A	A	3	0	5	20	
	WINDSCREEN ERECTION	O	A	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	F	A	O	O	O	A	F	A	F	5	3	0	20	X
	STREAMLINING																																	
	AFTERBODY	O	O	A	A	F	F	N	F	O	O	O	O	O	O	A	O	O	O	O	F	A	O	O	O	A	F	A	F	6	6	1	15	X
	DROGUE DRAG MODULATION	O	O	A	A	F	F	N	F	O	O	O	O	O	O	A	O	O	O	O	A	A	O	O	O	A	A	A	A	9	3	1	15	X
	MAIN PARACHUTES																																	
	BALLISTIC SPREADER	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	A	O	O	O	A	A	A	F	6	1	0	21	X
	REEFING	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	A	O	O	O	A	A	A	A	7	0	0	21	X
	AERO CONICAL	O	O	A	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	A	A	O	O	O	A	A	A	A	7	0	0	21	X

GRADING FORMAT

ACCEPTANCE CODE
- A = ACCEPTABLE
- F = FAIR
- N = NOT ACCEPTABLE
- O = NOT APPLICABLE

SYSTEMS FOR CONSIDERATION
CONSIDER IF
"ACCEPTABLE" 6 OR OVER
"NOT ACCEPTABLE" IS 0
DO NOT CONSIDER IF:
"NOT ACCEPTABLE" 3 OR OVER

Figure 62 Evaluation Matrix

		SPECIFIC REQUIREMENTS										
		RESTRAINT AGAINST EJECTION, WINDBLAST, AND DECELERATION FORCES				WINDBLAST PROTECTION	MAIN PARACHUTE PERFORMANCE IMPROVEMENT	STABILIZATION TO REDUCE VIOLENT, RANDOM MOTION	DECELERATION QUICKLY, WITHIN HUMAN TOLERANCE		SEAT/CREWMAN DRAG AREA REDUCTION	RESTRAINT SYSTEM INTEGRATOR
		HEAD	LEGS	ARMS	TORSO				<600 KTS.	>600 KTS.		
PROTECTIVE DEVICES	SEAT STRUCTURE	●	●		●							
	FLEXIBLE RESTRAINT		●	●	●							
	INFATABLE SUPPORT	●									●	
	FULL FACE HELMET					●						
	FEOTAL POSITIONING					●					●	
	45° EJECTION ANGLE					●					●	
	WINDSCREEN					●						
	MODULATED DROGUE							●	●			
	AFTERBODY							●	●	●		
	THRUST VECTOR CONTROL							●				
	D.A.R.T.							●				
	BALLISTIC SPREADER						●					
	REEFING						●					
	AERO-CONCIAL						●					
	CREWMAN GARMENT											●

Figure 63 Matrix for Selection of Crewman Retention System & Protective Devices

Table 1 Configuration 1 (Hands on Face Curtain) 98 Percentile Man Model Surface Data (Sheet 1 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
1	HEAD & SHOULDERS	20	0	+9.5	0	-37.5
2		33	+45°	+13.5	0	-37.5
3		44	+90°	+14.5	0	-32
4		23	+135°	+13.5	0	-28.5
5	UPPER RIGHT ARM	40	+76°	+10.5	+8	-19.5
6		68	+253°	+6	+8	-15.5
7	LOWER RIGHT ARM	16	+314°	+13.5	+6	-11
8		50	+319°	+13	+5	-16.5
9	RIGHT HAND	39	+300°	+20	+1.5	-19
10		39	+117°	+16.5	+1.5	-21
11	RIGHT THIGH & KNEE	110	+21°	+16	+5.5	-2.5
12		22	+60°	+25	+5	+2
13	RIGHT CALF	103	+104°	+23.5	+5.5	+14
14		100	+284°	+17	+5.5	+16

Table 1 Configuration 1 (Hands on Face Curtain) 98 Percentile Man Model Surface Data (Sheet 2 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
15	RIGHT FOOT	34	+18.5°	+24.5	+6	+25
16		63	+195°	+23.5	+6	+27
17		11	+104°	+27.5	+6	+27.5
18	UPPER LEFT ARM	40	+76°	+10.5	-8	-19.5
19		68	+253°	+6	-8	-15.5
20	LOWER LEFT ARM	16	+314°	+13.5	-6	-11
21		50	+139°	+13	-5	-16.5
22	LEFT HAND	39	+300°	+20	-1.5	-19
23		39	+117°	+16.5	-1.5	-21
24	LEFT THIGH & KNEE	110	+21°	+16	-5.5	-2.5
25		22	+60°	+25	-5	+2
26	LEFT CALF	103	+104°	+23.5	-5.5	+14
27		100	+284°	+17	-5.5	+16

Table 1 Configuration 1 (Hands on Face Curtain) 98 Percentile Man Model Surface Data (Sheet 3 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
28	LEFT	34	+18.5°	+24.5	-6	+25
29	FOOT	63	+195°	+23.5	-6	+27
30		11	+104°	+27.5	-6	+27.5
31	TORSO	50	+66°	+13	0	-23
32		154	+90°	+14	0	-9.5

Table 2 Configuration 2 (Hands on Alternate Firing Handle) 98 Percentile Man Model Surface Data (Sheet 1 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
1	HEAD & SHOULDERS	20	0	+9.5	0	-37.5
2		33	+45°	+13.5	0	-35.5
3		44	+90°	+14.5	0	-32
4		23	+135°	+13.5	0	-28.5
5	UPPER RIGHT ARM	44	+90°	+10	+9	-17
6		61	+264°	+4.5		-16.5
7	LOWER RIGHT ARM	40	+36°	+13.5	+8.5	-8.5
8		44	+205°	+10.5	+8.5	-5
9	RIGHT HAND	32	+22°	+19	+3.5	-3
10		32	+198°	+17	+3.5	-4
11	RIGHT THIGH & KNEE	110	+21°	+16	+5.5	-2.5
12		22	+60°	+25	+5	+2
13	RIGHT CALF	103	+104°	+23.5	+5.5	+14
14		100	+284°	+17	+5.5	+16

Table 2 Configuration 2 (Hands on Alternate Firing Handle) 98 Percentile Man Model Surface Data (Sheet 2 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
15	RIGHT	34	+18.5°	+24.5	+6	+25
16	FOOT	63	+195°	+23.5	+6	+27
17		11	+104°	+27.5	+6	+27.5
18	UPPER LEFT	44	+90°	+10	-9	-17
19	ARM	61	+264°	+4.5	-9	-16.5
20	LOWER LEFT	40	+36°	+13.5	-8.5	-8.5
21	ARM	44	+205°	+10.5	-8.5	-5
22	LEFT	32	+22°	+19	-3.5	-3
23	HAND	32	+198°	+17	-3.5	-4
24	LEFT THIGH &	110	+21°	+16	-5.5	-2.5
25	KNEE	22	+60°	+25	-5	+2
26	LEFT	103	+104°	+23.5	-5.5	+14
27	CALF	100	+284°	+17	-5.5	+16

Table 2 Configuration 2 (Hands on Alternate Firing Handle) 98 Percentile Man Model Surface Data (Sheet 3 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
28	LEFT FOOT	34	+18.5°	+24.5	-6	+25
29		63	+195°	+23.5	-6	+27
30		11	+104°	+27.5	-6	+27.5
31	TORSO	81	+66°	+13	0	-23
32		162	+90°	+14	0	-13

Table 3 Configuration 3 (Hands on Thighs) 98 Percentile Man Model Surface Data (Sheet 1 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
1	HEAD & SHOULDERS	20	0	+9.5	0	-37.5
2		33	+45°	+13.5	0	-35.5
3		44	+90°	+14.5	0	-32
4		23	+135°	+13.5	0	-28.5
5	UPPER RIGHT ARM	44	+104°	+7	+11	-17
6		50	+278°	+3	+11	-17
7	LOWER RIGHT ARM	38	+37°	+11.5	+11	-8
8		47	+211°	+8	+11	-6
9	RIGHT HAND	28	+37°	+18.5	+8	-3
10		28	+ 211°	+16.5	+8	-0.5
11	RIGHT THIGH & KNEE	110	+21°	+16	+5	-2.5
12		22	+60°	+25	+5	+2
13	RIGHT CALF	103	+104°	+23.5	+5.5	+14
14		100	+284°	+17	+5.5	+16

Table 3 Configuration 3 (Hands on Thighs) 98 Percentile Man Model Surface Data (Sheet 2 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
15	RIGHT	34	+18.5°	+24.5	+6	+25
16	FOOT	63	+195°	+23.5	+6	+27
17		11	+104°	+27.5	+6	+27
18	UPPER LEFT	44	+104°	+7	-11	-17
19	ARM	50	+278°	+3	-11	-17
20	LOWER LEFT	38	+37°	+11.5	-11	-8
21	ARM	47	+211°	+8	-11	-6
22	LEFT	28	+37°	+18.5	-8	-3
23	HAND	28	+211°	+16.5	-8	-0.5
24	LEFT THIGH &	110	+21°	+16	-5	-2.5
25	KNEE	22	+60°	+25	-5	+2
26	LEFT	103	+104°	+23.5	-5.5	+14
27	CALF	100	+284°	+17	-5.5	+16

Table 3 Configuration 3 (Hands on Thighs) 98 Percentile Man Model Surface Data (Sheet 3 of 3)

SURFACE	PART OF BODY	AREA (IN^2)	θ (REL. TO X-AXIS) CW (+)	X_i (IN)	Y_i (IN)	Z_i (IN)
28	LEFT	34	+18.5°	+24.5	-6	+25
29	FOOT	63	+195°	+23.5	-6	+27
30		11	+104°	+27.5	-6	+27.5
31	TORSO	81	+66°	+13	0	-23
32		216	+90°	+13.5	0	-12

Table 4 Weight – Location – Configuration 98 Percentile Man Model Body Parts

BODY PART	WEIGHT	CONFIGURATION 1 X	1 Y	1 Z	2 X	2 Y	2 Z	3 X	3 Y	3 Z
HEAD	20	+9.5	0	-32	+9.5	0	-32	+9.5	0	-32
TRUNK-NECK	132	+5	0	-16	+5	0	-16	+5	0	-16
UPPER ARM – RIGHT	7.5	+8.5	+8	-16.5	+7	+9	-16	+5.5	+10	-17
UPPER ARM – LEFT	7.5	+8.5	-8	-16.5	+7	-9	-16	+5.5	-10	-17
LOWER ARM – RIGHT	4.8	+12	+6.5	-12	+11.5	+8.5	-7	+8.5	+10.5	-8
LOWER ARM – LEFT	4.8	+12	-6.5	-12	+11.5	-8.5	-7	+8.5	-10.5	-8
HAND – RIGHT	1.8	+18	+1.5	-20.5	+18	+3.5	-3.5	+17.5	+8	-2
HAND – LEFT	1.8	+18	-1.5	-20.5	+18	-3.5	-3.5	+17.5	-8	-2
UPPER LEG – RIGHT	24.3	+13	+5	+1	+13	+5	+1	+13	+5	+1
UPPER LEG – LEFT	24.3	+13	-5	+1	+13	-5	+1	+13	-5	+1
LOWER LEG – RIGHT	10.9	+20.5	+5.5	+12	+20.5	+5.5	+12	+20.5	+5.5	+12
LOWER LEG – LEFT	10.9	+20.5	-5.5	+12	+20.5	-5.5	+12	+20.5	-5.5	+12
FOOT – RIGHT	6	+20.5	+6	+25.5	+20.5	+6	+25.5	+20.5	+6	+25.5
FOOT – LEFT	6	+25.5	-6	+25.5	+20.5	-6	+25.5	+20.5	-6	+25.5

CONFIGURATIONS 1, 2 3
SEAT – MAN
C.G. LOCATIONS ~ INCHES

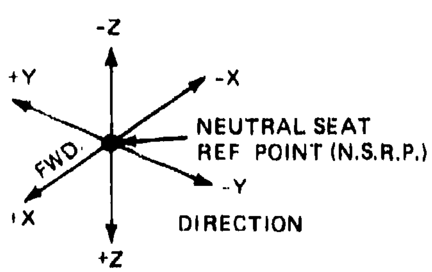
XSMCG = +5.6 IN.
YSMCG = 0.0 IN.
ZSMCG = -9.5 IN.

CONFIGURATIONS

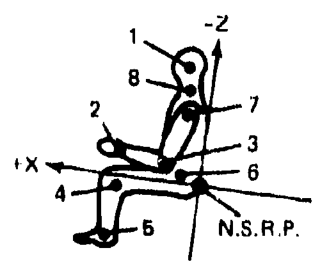
1 – HANDS ON FACE CURTAIN
2 – HANDS ON ALTERNATE FIRING HANDLE
3 – HANDS ON THIGHS

Table 5 Point Locations 98 Percentile Man Model

POINT	CONFIGURATION	DISTANCE FROM N.S.R.P.		
		X	Y	Z
1 HEAD	1 2 3	+9.5 +9.5 +9.5	0 0 0	-32 -32 -32
2 WRIST	1 2 3	+17 +17 +14	±4 ±7 ±9	-15 -4 -4
3 ELBOW	1 2 3	+10.5 +8 +4.5	±8 ±10 ±11	-10 -9 -10.5
4 KNEE	1 2 3	+23 +23 +23	±6 ±6 ±6	+3 +3 +3
5 ANKLE	1 2 3	+18.5 +18.5 +18.5	±6 ±6 ±6	+22 +22 +22
6 HIP	1 2 3	+6 +6 +6	±7 ±7 ±7	-1.5 -1.5 -1.5
7 SHOULDER JOINT	1 2 3	+6.5 +6.5 +6.5	±7.5 ±7.5 ±7.5	-23 -23 -23
8 BASE SKULL ON SPINE	1 2 3	+8.5 +8.5 +8.5	0 0 0	-30 -30 -30



DIRECTION



POINTS

Table 6 Maximum Body Wind Blast Forces 600 Kts – Sea Level – Configuration 2

MEMBER	TIME–SEC	RESULTANT FORCE–LB	TIME–SEC	X–FORCE COMP	TIME–SEC	Z–FORCE COMP
– –HEAD– –	0.35300	513.042	0.34600	511.133	0.50299	-266.631
R–UP–ARM	0.36800	309.458	0.36800	300.266	0.36800	-74.865
R–LW–ARM	0.27800	279.238	0.27800	183.196	0.27800	210.743
–R–HAND–	0.27800	306.061	0.27800	272.702	0.27800	138.949
R–UP–LEG	0.51099	872.497	0.51099	385.533	0.51099	-782.697
R–LW–LEG	0.27800	845.454	0.27800	820.340	0.27800	204.533
–R–FOOT–	1.05096	263.117	0.27800	87.927	1.05096	254.151
L–UP–ARM	0.36800	309.458	0.36800	300.266	0.36800	-74.865
L–LW–ARM	0.27800	279.238	0.27800	183.196	0.27800	210.743
–L–HAND–	0.27800	306.061	0.27800	272.702	0.27800	138.949
L–UP–LEG	0.51099	872.497	0.51099	385.533	0.51099	-782.697
L–LW–LEG	0.27800	845.454	0.27800	820.340	0.27800	204.533
–L–FOOT–	1.05096	263.117	0.27800	87.927	1.05096	254.151
– TORSO –	0.35300	1511.559	0.35300	1505.057	0.39100	-155.820

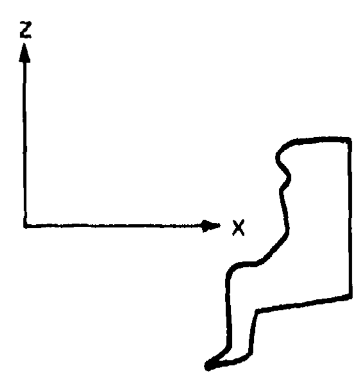


Table 7 Max. Surface Pressures and Forces 600 Kts. S.L. Configuration 2

TIME–SEC	PANELS	PRESSURE–PSF	NORM VEL–FPS	TANG VEL–FPS	X--FORCE COMP–LB	Z–FORCE COMP–LB	NORM FORCE.–LB
0.51799	1.00	749.04	793.875	502.832	0.0	-104.033	104.033
0.43600	2.00	1081.14	953.765	70.381	175.194	-175.194	247.762
0.33800	3.00	1155.08	985.838	45.798	352.940	-0.000	352.940
0.27800	4.00	880.08	860.522	507.980	99.397	99.397	140.569
0.33800	5.00	1137.24	978.197	43.507	347.490	-0.000	347.490
1.02797	6.00	111.80	306.703	636.457	-47.100	4.950	47.359
0.47299	7.00	1053.61	941.542	20.523	172.026	-236.774	292.669
1.02098	8.00	589.93	704.531	81.329	-76.180	163.368	180.257
0.51099	9.00	1016.66	924.432	171.499	84.550	-209.268	225.703
1.01298	10.00	593.51	706.668	38.014	-40.757	125.437	131.892
0.51099	11.00	1009.02	921.405	187.543	276.223	-719.587	770.782
0.40600	12.00	1052.08	940.858	33.767	139.200	-80.367	160.734
0.27800	13.00	1181.99	997.258	8.853	820.340	204.533	845.454
1.02797	14.00	5.58	68.523	701.568	-3.760	-0.938	3.875
0.51799	15.00	989.38	912.390	224.932	74.123	-221.531	233.603
1.05096	16.00	601.41	711.353	3.062	-68.100	254.151	263.117
0.27800	17.00	1180.53	996.638	9.175	87.500	21.816	90.179
0.33800	18.00	1137.24	978.197	43.507	347.490	-0.000	347.490
1.02797	19.00	111.80	306.703	636.457	-47.100	4.950	47.359
0.47299	20.00	1053.61	941.542	20.523	172.026	-236.774	292.669
1.02098	21.00	589.93	704.531	81.329	-76.180	163.368	180.257
0.51099	22.00	1016.66	924.432	171.499	84.550	-209.268	225.703
1.01298	23.00	593.51	706.668	38.014	-40.757	125.437	131.892
0.51099	24.00	1009.02	921.405	187.543	276.223	-719.587	770.782
0.40600	25.00	1052.08	940.858	33.767	139.200	-80.367	160.734
0.27800	26.00	1181.99	997.258	8.853	820.340	204.533	845.454
1.02797	2700	5.58	68.523	701.568	-3.760	-0.938	3.875
0.51799	28.00	989.38	912.390	224.932	74.123	-221.531	233.603
1.05096	29.00	601.41	711.353	3.062	-68.100	254.151	263.117
0.27800	30.00	1180.53	996.638	9.175	87.500	21.816	90.179
0.39100	31.00	1103.32	963.498	55.356	566.963	-252.429	620.618
0.33800	32.00	1132.61	976.159	45.547	1274.072	-0.000	1274.072

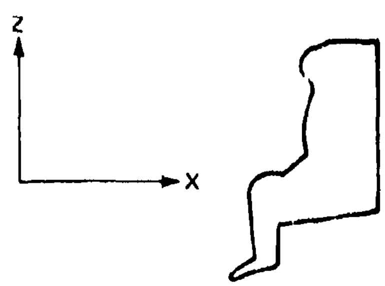
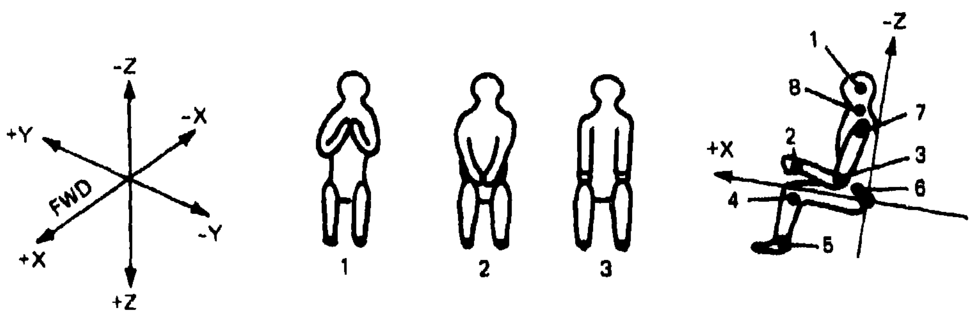


Table 8 Maximum Restraint Forces

POINT	CONFIGURATION	MAXIMUM FORCE IN POUNDS		
		X	Y	Z
1 HEAD	1 2 3	-260 -260 -260	±260 ±260 ±260	+570 +570 +570
2 WRIST	1 2 3	-205 -154 -154	±205 ±154 ±154	+113 +100 +100
3 ELBOW	1 2 3	-126 -208 -208	±126 ±208 ±208	+297 +245 +245
4 KNEE	1 2 3	*	±988 ±988 ±988	+766 +766 +766
5 ANKLE	1 2 3	-360 -360 -360	±957 ±957 ±957	**



DIRECTION OF RESTRAINT FORCE

CONFIGURATIONS

POINTS

* FORCE RESTRAINED BY SEAT-TORSO RESTRAINT SYSTEM.
** FORCE RESTRAINED BY KNEE RESTRAINT.

Table 9 Air Crewmen Personnel Equipment Damage Investigation During Ejections Sled Test Data (Sheet 1 of 3)

TEST VELOCITY KEAS	SLED	DUMMY SIZE -ILE CREW STATION	EJECTED WT LBS	RECORDED DAMAGE: EJECTION MODE	GARMENT	SURVIVAL EQUIPMENT	DROGUE CHUTE SYSTEM	MAIN CHUTE SYSTEM	REF. STILL PHOTO NUMBER AND DATE	REF. MOTION PICTURE FILM
435	F-14*	98 NFO	478	Canopy Off	Rip in flight suit on right arm 12" long	Life Vest (LPA-1) Inflated on ground impact	No damage	L shape tear 12" x 12" in Panel C Gore 13, 1" dia. hole in Panel B Gore 2, 5" long tear along seam in Panel C of Gore 8 and L shape tear in Panel B of Gore 9.	152692 11/3/70 152691 11/3/70	Reel No. 3 of Appendix I to GAC Results Report No. A51-314-R-91.14 dated 13 December 1970
435	F-14	3 Pilot	377	Canopy Off	No damage	No damage	No damage	1" dia. hole in Panel D Gore 18, 1" tear in water pocket of Gore 13, and a 2" tear in Panel C of Gore 15	152694 11/30/70 152695 11/30/70	
600	F-14	3 NFO	378	Canopy Off	Minor tears on left shoulder and left leg. Sunvisor, initially in stowed position was missing	Oxygen mask found scraped and approximately 5' from dummy on landing	Minor tear damage to 5' drogue	Main chute lost Panel C in Gore 13, with several minor burns and holes in rest of chute	153112 11/17/70 153110 11/17/70	Reel No. 4 of Appendix I to GAC Results Report No. A51-314-R-91.14 dated 13 December 1970
600	F-14	98/Pilot	480	Canopy Off	Tear damage in various parts of exposure suit. Left boot was blown off as crewmen emerged from vehicle. Scrape on dummy's chin. Sun visor initially stowed was missing.	Equipment pockets on survival vest came undone.	5' drogue chute completely destroyed no damage to 22" controller drogue.	Main chute lost panels A and B in Gore 8 and incurred many minor burns and small holes around the apex area, including slight separation of material from band at the apex.	153109 11/17/70 153108 11/17/70 153106 11/17/70 153100 11/17/70	
450	A-6A**	5/BN	379	Thru Canopy Glass	Minor fraying on right arm and back of harness. Scrape on left side of Helmet.	No damage	Tear 1" long in 5' drogue	1" long tear in Panel C Gore 13, 6" long tear in Panel D Gore 14, 1" dia. Hole in Panel C Gore 14.	153165 11/23/70 153167 11/23/70 153168 11/23/70 153169 11/23/70	Reel No. 1 of Appendix I to GAC Results Report No. 4146.45 dated 12 March 1971
450	A-6A	95/Pilot	474	Thru Canopy Glass	Sun visor broken, rip 4" long on right arm, rip from 2" below elbow up to left shoulder.	No damage	No damage	No damage	153163 11/23/70 153158 11/23/70 153161 11/23/70	
500	A-6A	95/BN	471	Thru Canopy Glass	Dummy's left arm broken off at shoulder joint. Helmet visors and guard broken off. Minor fraying on both legs of exposure suit, 12" rip in exposure suit right arm.	Both L.H. and R.H. Y Straps on the survival kit failed at the Y attachment point. The kit opened and the raft came out.	5' drogue had 9 panels blown. 22" controller and strap	Main chute lost Panels A and B. In Gore 28, 1" long tear in Panel C, of Gore 4, minor burns and small holes in several other gores.	153434 12/1/70 153435 12/1/70 153436 12/1/70 153437 12/1/70 153439 12/1/70 153440 12/1/70 153441 12/1/70 153442 12/1/70 153443 12/1/70 153432 12/1/70	Reel No. 2 of Appendix I to GAC Results Report No. 4146.45 dated 12 March 1971

Table 9 Air Crewmen Personnel Equipment Damage Investigation During Ejections Sled Test Data (Sheet 2 of 3)

TEST VELOCITY KEAS	SLED	DUMMY SIZE %ILE CREW STATION	EJECTED WT LBS	EJECTION MODE	RECORDED DAMAGE				REF. STILL PHOTO NUMBER AND DATE	REF. MOTION PICTURE FILM
					GARMENT	SURVIVAL EQUIPMENT	DROGUE CHUTE SYSTEM	MAIN CHUTE SYSTEM		
600	A-6A	5 Pilot	382	Thru Canopy Glass	Fraying on left and right elbows, scrape on toe of left shoe sun visor broken	Survival kit opened	No damage	Main chute had 1" and 2" holes in Panel D, Gore 1 as well as one minor burn tear in Panel C, Gore 14.	153444 12/1/70 153446 12/1/70 153447 12/1/70 153448 12/1/70 153449 12/1/70 153451 12/1/70	Reel No. 2 of Appendix I to GAC Results Rep. No. 4146.46 dated 12 March 1971
450	EA6B	5 Aft Right	332	Thru Canopy Glass	Right arm of dummy was broken off but this can be attributed to contacting the trackside structure	No damage	No damage	Pilot chute sustained small holes. On main chute panel =21 blown, two-quarter panels at apex blown	145947 12/13/69	Reel No. 5 of Appendix IV to GAC Results Report No. 4133.46B dated 1 August 1970
450	EA6B	95 Aft Left	425	Thru Canopy Glass	Dummy suffered tear in right sleeve and flesh at that point and right shoulder was wrenched back over stops. (Attributed to ground contact)	No damage	Drouge and main chute system were destroyed by the pusher sled which caught them as they lay draped over the track making it impossible to determine if they sustained any damage.		145949 12/13/69	
450	EA6B	95 Fwd Right	422	Thru Canopy Glass	Dummy sustained tears in the exposure suit left and right arms (May have been due to ground contact)	No damage	No damage	A strap in the torso harness to which one of the parachute risers is attached failed and the dummy was in effect attached to the chute by only one riser. (Harness failure may have been due to extreme repeated use).	145951 12/13/69 145950 12/13/69	
450	EA6B	5 Fwd Left	335	Thru Canopy Glass	Test Invalid, Escape System Malfunctioned					

Table 9 Air Crewmen Personnel Equipment Damage Investigation During Ejections Sled Test Data (Sheet 3 of 3)

TEST VELOCITY KEAS	SLED	DUMMY SIZE %ILE CREW STATION	EJECTED WT. LBS.	EJECTION MODE	RECORDED DAMAGE: GARMENT	RECORDED DAMAGE: SURVIVAL EQUIPMENT	RECORDED DAMAGE: DROGUE CHUTE SYSTEM	RECORDED DAMAGE: MAIN CHUTE SYSTEM	REF. STILL PHOTO NUMBER AND DATE	REF. MOTION PICTURE FILM
600	EA6B	95 Fwd Right		Thru Canopy Glass	Pieces of uniform were torn off and shed immediately before and after cat tube separation helmet was torn off. Torso harness was pulled down off shoulders.	Life vest was torn open and survival kit was broken loose.	Tubular woven cover on main drogue line completely parted in the middle. Approximately 4" hole in panel of drogue chute.	Main chute inflated approximately 85% prior to ground impact. Left stow bag had some line length left in. Main canopy had holes in upper and lower portions of Panel 2. Panel 4 in upper portion and Panel 21 in middle portion. Pilot chute had a tear and a broken spring.	147109 thru 147114 2/20/70	Reel No. 7 of Appendix IV to GAC Results Report No. 4133.458 dated 1 August 1970
600	EA6B	5 Fwd Left		Thru Canopy Glass	Dummy sustained severe damage on ground impact (see photos) with the main chute approximately 70% inflated at about 10 to 20 degrees. Damage too extensive to determine if any attributed to wind blast.		Drogue chute had one suspension line broken.	Main chute left hand anti-squid line failed in the main body and not at the control section. A small hole was noted in the lower portion of Panel =1. The pilot chute sustained a small hole.	147118 2/20/70 147119 2/20/70 147120 2/20/70 147115 2/20/70 147117 2/20/70	

* Ref. GAC F-14A Results Report No. A51-314-R-91.14 dated 31 December 1970

** Ref. GAC A-6A Results Report No. 4146.45 dated 12 March 1971

*** Ref. GAC EA6B Results Report No. 4133.458 dated 1 August 1970

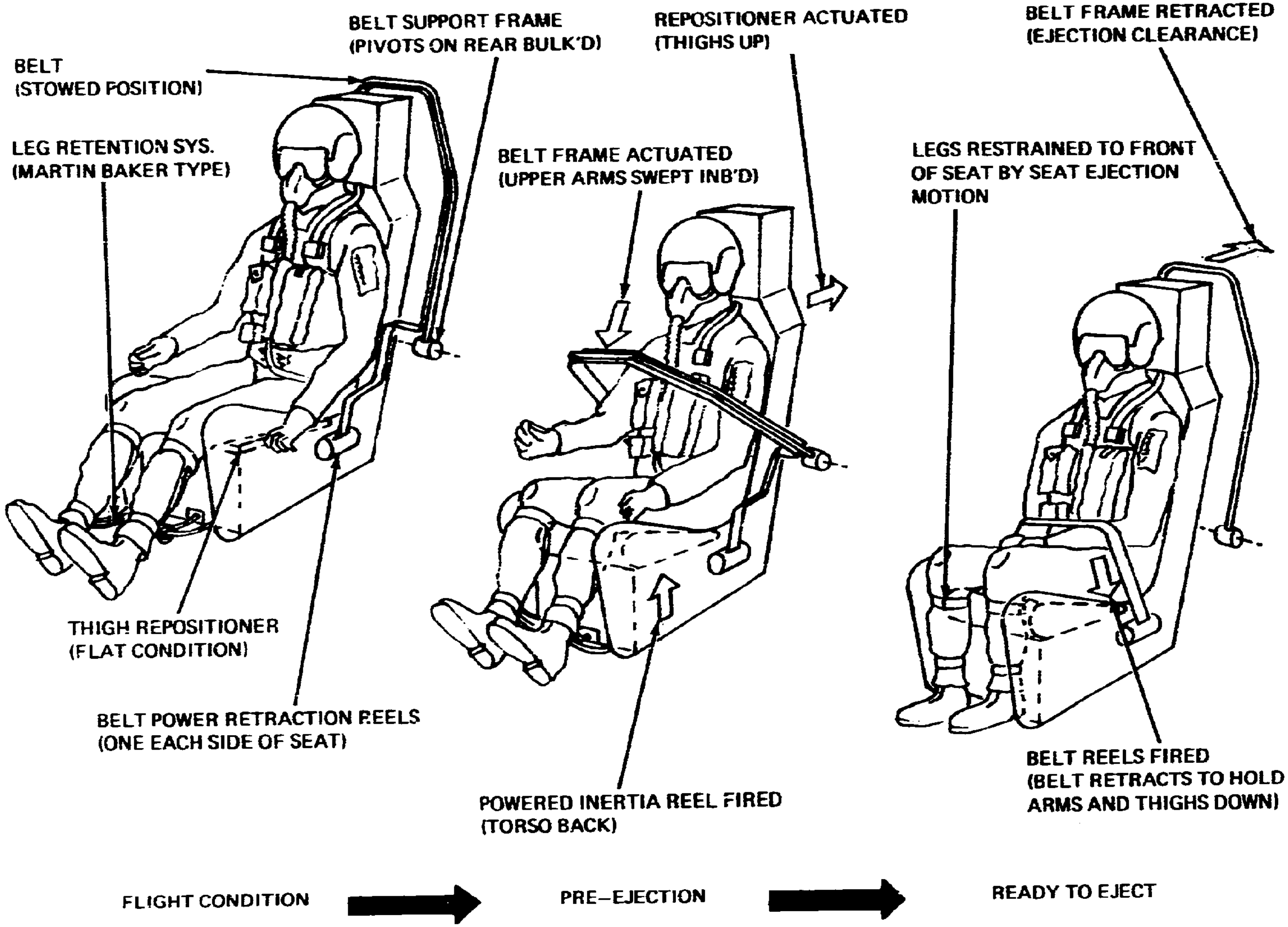


Figure 64 Belt Grabber Restraint

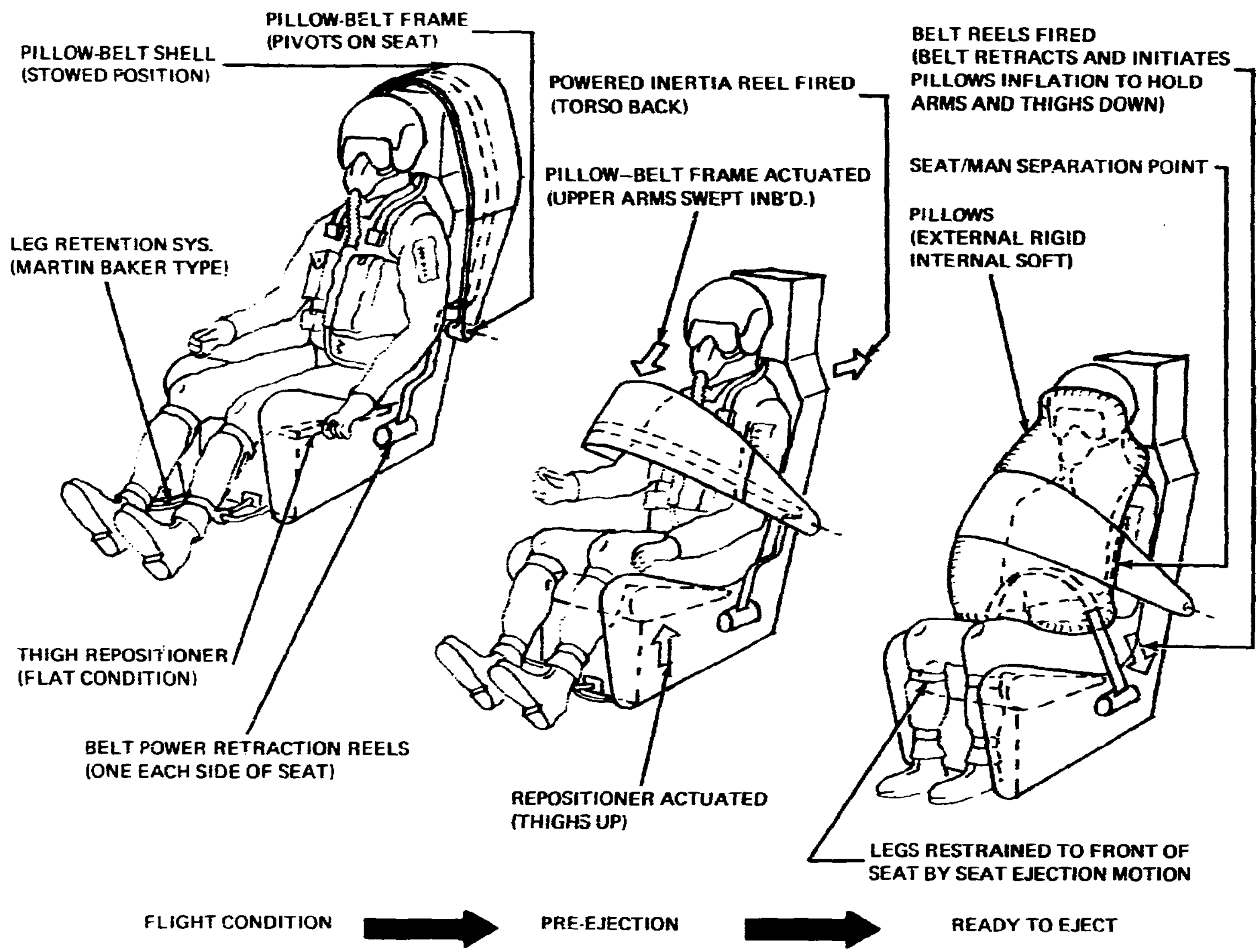


Figure 65 Pillow/Belt Grabber Restraint

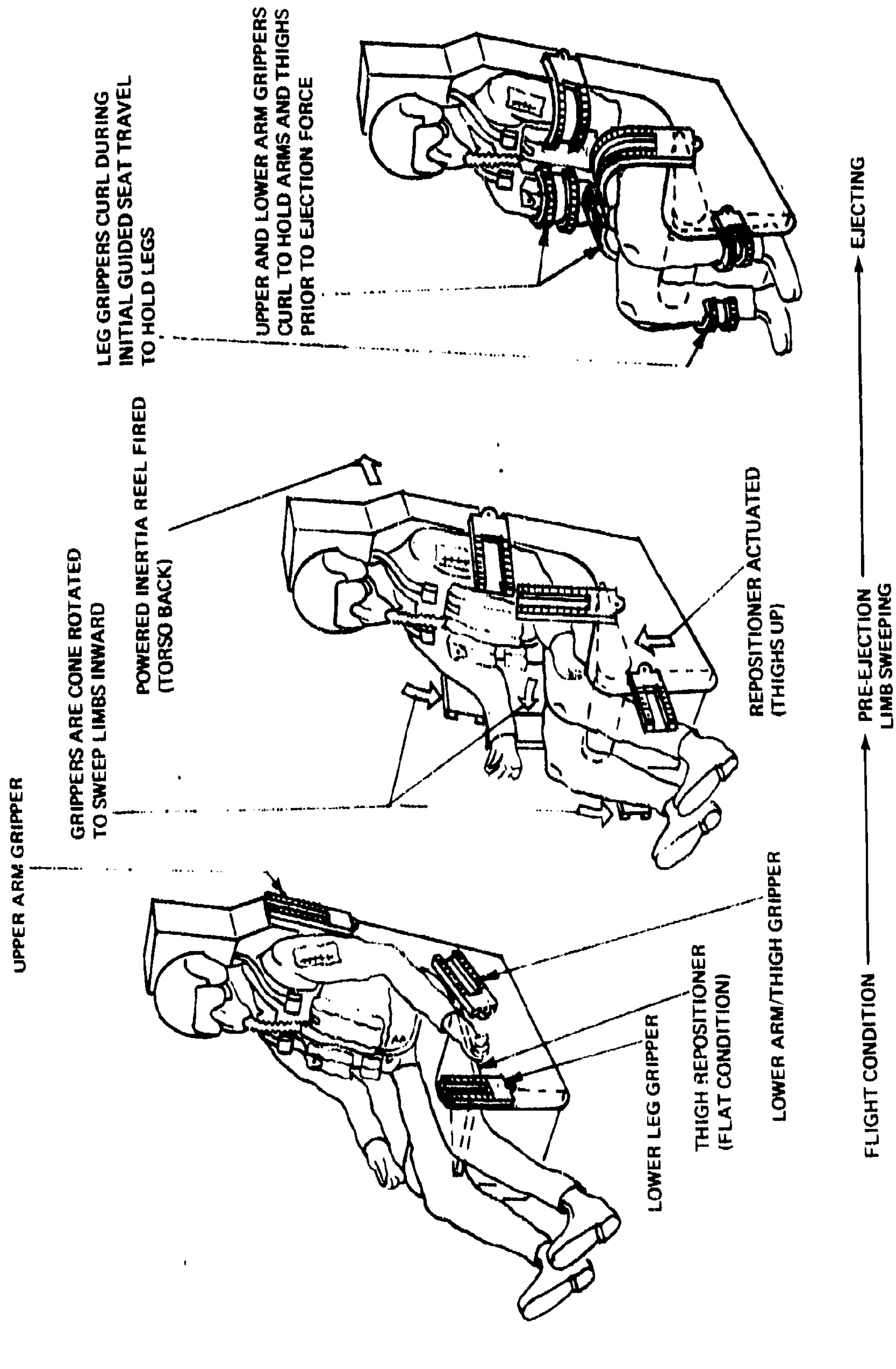
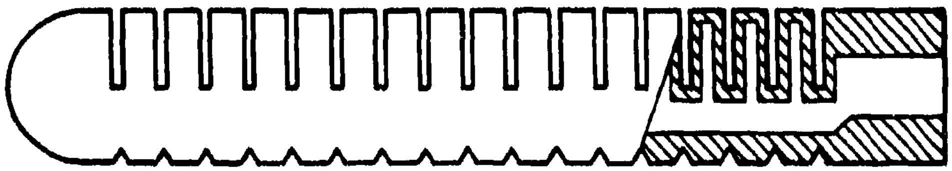
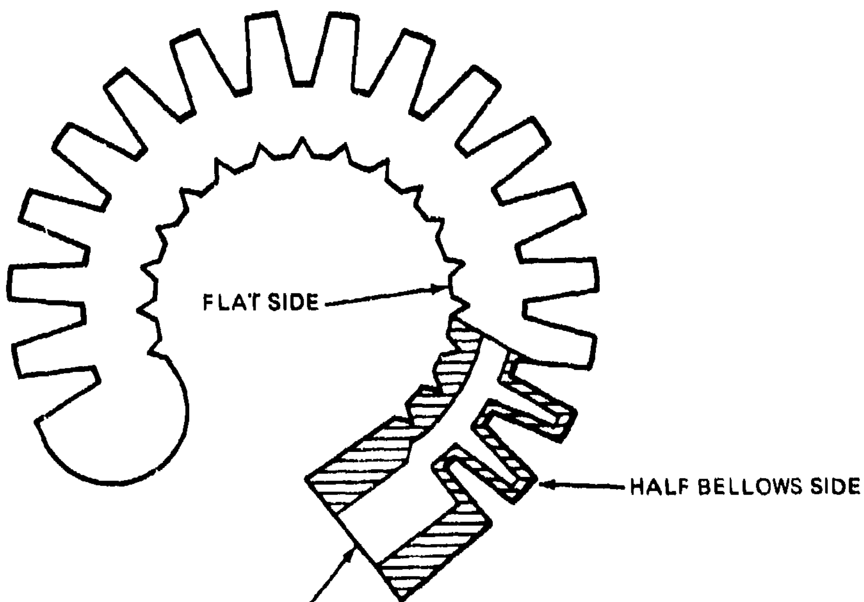


Figure 66 Sweep and Grip Restraint (Sheet 1 of 2)

OPERATIONAL CONCEPT
OF GRIPPER SYSTEM ELEMENT



ELEMENT AT REST



PRESSURE INPUT CAUSES THE ELEMENT TO CURL AS SHOWN.
THE HALF BELLOWS SIDE ELONGATES WHILE THE FLAT SIDE DOES NOT.
THIS UNEQUAL EXPANSION FORCES THE FLAT SIDE TO CURL INWARD.
GRIPPING FORCE IS DEVELOPED BY DIAPHRAGM ACTION OF BELLOWS.

ELEMENT ACTUATED

Figure 66 Sweep and Grip Restraint (Sheet 2 of 2)

LIST OF REFERENCES

REFERENCE	TITLE
1	Grumman Aerospace Corporation Program, "Six-Degree-of-Freedom Seat Ejection Seat Trajectory Program"
2	Air Force Flight Dynamics Laboratory, "Aeromechanical Properties of Ejection Seat Escape Systems", B. J. White, Technical Report AFFDL-TR-74-57, April, 1974
3	Air Force Flight Dynamics Laboratory, "Performance of and Design Criteria for Deployable Aerodynamic Decelerators", Technical Report ASD-TR-61-579, December, 1963.
4	Air Force Flight Dynamics Laboratory, "Fluidic Thrust Vector Control for the Stabilization of Man/Ejection Seat Systems", Honeywell, Inc. Technical Report AFFDL-TR-75-105, September 1975
5	Aerospace Medical Research Laboratory "The Heat Pulse Associated with Escape from an Aircraft at Supersonic Speed", Payne, Inc. Technical Report AMRL-TR-76-2, June, 1976
6	Advisory Group for Aerospace Research and Development, "AGARD Conference Proceedings No. 134 on Escape Problems and Maneuvers in Combat Aircraft"
7	Advisory Group for Aerospace Research and Development, "AGARD Conference Proceedings No. 170 on Biodynamic Response to Windblast"
8	Naval Safety Center, Naval Air Station, Norfolk, Va. Calendar Year Publication, "Emergency Airborne Escape Summary", covering a report of Ejections and Bailouts from Navy aircraft.

LIST OF REFERENCES (Cont.)

REFERENCE	TITLE
9	Rice, E. V., and E. H. Ninow, "Man-Machine Interface: A Study of Injuries Incurred During Ejection from U.S. Navy Aircraft", Aerospace Medicine 44(1): 87-89, 1973.
10	Grumman Aerospace Corporation Report No. ADR06-07-73.1, April 1973, "High $\bar{q}$ Open Ejection Seat System, Phase Ic Study"

APPENDIX A

PHYSIOLOGICAL TOLERANCE TO ACCELERATION AND DECELERATION FORCES (AN UPDATE OF THE LITERATURE)

SUMMARY

An up-to-date study of the literature was conducted in order to assemble into one report information and findings on man's tolerance to G forces. The necessity of this study resulted from the wide differences in the data previously reported and the attempt to standardize the values.

The immediate purpose of the study was to update the acceleration and deceleration data currently being used by our Life Sciences personnel and concerned design engineers, for this study.

INTRODUCTION

The major purpose of this report is to present the latest available information and findings on man's tolerance to G forces. This is necessary because of the differences in the data reported and as an attempt to standardize these values. The practical purpose of this study is to update the values we are presently utilizing in the design of a restraint system.

In this report, all types of G application are reviewed. Data which are reported as extrapolated are specified as so. Actual test data were obtained from centrifuge, propelled sled, drop tests and ejection seat studies.

Reports of both low and high G onset rates are evaluated and corresponding G tolerances specified. In every instance end points reached are defined so as to leave no doubt in the reader's mind as to the meaning and interpretation of the data.

DISCUSSION

THEORY

The range of acceleration environments is quite large and human tolerance to accelerative and decelerative loads varies to a considerable extent. Tolerance to these forces is based on:

- The magnitude of the force applied
- The duration of applied force
- The rate of onset and decline
- The direction of the G vector (relationship of the vector of the force to the axis of the body)
- The physical properties of the human body which define the response of the individual components of the body to the object which serves to transmit the force to the body.

Acceleration involves, essentially, the reaction of a force upon an object or parts of an object. Since the object may be part of man's body, an understanding of the physiological mechanisms involved is of considerable value.

Positive acceleration (G forces) have three main sites at which they produce their effects: the body as a whole, the viscera and the cardiovascular system.

Negative acceleration, force applied from foot to head, will result in an increased arterial pressure at the head level. Gravitation in the foot to head direction will also lead to eventual circulatory distress if sufficiently prolonged.

Since the force of transverse g does not interfere significantly with the flow of blood in the body, man is much more tolerant to transverse g than either positive or negative g.

Lateral acceleration, G forces acting on the side of a person perpendicular to the longitudinal axis of the body causes a temporary displacement of the heart and lungs.

Man's tolerance to accelerative and decelerative forces ranges from no-injury to possible injury. Any force exceeding this tolerance would then result in injury and finally death. When we discuss man's tolerance to G we are considering that G which when applied will not produce any effect on the man that will prevent him from functioning in the vehicle. Therefore man's tolerance to G, as thus defined, is considerably less than if he were required to tolerate the G without performing a function, with a guarantee that the effects would be neither permanent or painful.

Motion in the direction is just possible at the vehicle accelerations designated:

- Raising the arm above the head: 6G
- Moving the head forward and aft, left and right: 4G
- Raising the arm from the armrest: 8G
- Raising the hand off the armrest control: 25G
- Raising the knee: 3G
- Moving the foot fore and aft: 5G
- Raising the foot: 3G.

When considering the limitations above, it is understood that these G's are experienced by the man. It is therefore, reasonable to assume that the vehicle will be subjected to less than this (in which case there is an over-shoot on the man); the same as this (in which case the vehicle and man can be considered as one); or more than this (in which case some of the G is absorbed and/or attenuated before it reaches man).

In any case, these G's are the motion limitations. These values are derived from centrifuge studies where the vehicle has not been considered. It may be that in the vehicle under consideration, these motion limitations exceed the stress capability of the vehicle, in which case they are not of practical significance.

Another consideration when evaluating the motion limitations is performance requirements. Performance degradation, among other things, is a function of G, and may be considered as directly proportional. Man's ability to functionally perform while being subjected to G force is a more delicate consideration than motion capabilities under the same stress.

Blackout and redout are common occurrences at even low magnitude of accelerative and/or decelerative forces. Incapacitation in this situation might well occur before reaching man's motion limitations. Therefore in conclusion:

- Man's motion limitations and capabilities are given without regard to vehicle capabilities
- It is assumed that performance degradation will occur prior to reaching some of the motion limitations
- Stress limitations of the vehicle should be considered before imposing the requirements on man
- Physiological tolerance to accelerative and decelerative forces are based on no-injury criteria.

Some acceleration exposures may be so moderate that they have relatively little or no physiological or psychological effects, or they may become severe enough to produce major disturbances. The emphasis here is on physiological tolerance which could be modified by sustained acceleration. The unit for the physiological acceleration is G, as distinguished from the "true" displacement acceleration, generally designated by aerodynamicists with the unit g. The physiological acceleration represents the total reactive force divided by the body mass, and includes both displacement and resisted gravitational acceleration effects. The physiological axes represent directions of the reactive displacements of organs and tissues with respect to the skeleton system. The Z axis is down, with the $+G_z$ (unit vectors) designations for accelerations causing the heart, etc. to displace downward (caudally). The X axis is front to back, with the $+G_x$ designations for accelerations causing the heart to be displaced back toward the spine (dorsally). The Y axis is right to left, with the $+G_y$ designations for accelerations causing the heart to be displaced to the left.

Man's tolerance to sustained positive acceleration is inversely proportional to G onset. Studies show that the duration at a particular G level is significant and is a function of G onset rate. The G onset rate is in units of G/second (G/S) and is a measure of the rate of change of acceleration. It is the first time derivative of acceleration, the second time derivative of velocity, and the third time derivative of displacement. The lower the onset rate, the longer the time before the end-point (gray out, black-out, confusion, possible to a point of unconsciousness) is reached or the longer the duration of the max G endured with less serious consequences.

In searching for data concerning the physiological limits to acceleration for short pulse periods of less than .1 second, the literature yields data that are for longer periods of time and in some cases extrapolated from existing data. The data consist mainly of subjective symptoms experienced as a result of acceleration and so as not to exceed the voluntary human tolerance level, these subjective symptoms served as the end-point for G determination. Investigators in most cases went one step further and extrapolated data to determine ultimate physiological limits and concluded that on the basis of subjective symptoms if G's were increased or prolonged, further physiological damage would result. They also concluded that for the same magnitude of G's or of greater magnitude, G's could be better tolerated for shorter periods of time.

In order to obtain physiological limits which will be universally acceptable regarding a "no-injury", "injury", and "fatal" zone caused by accelerative forces in all planes, it is desirable that some standardization be introduced with regard to subject groups, units of measurement, fixed values of forces not under investigation, and methods of experimental measurement.

EQUIPMENT

Among the instruments available to create and thus measure the amount of G force applied on the body are the human centrifuge, drop tower and the accelerometer. The former is also used to test human tolerance to various magnitudes and duration of G forces and is equipped to record various significant physiological changes produced on a body subjected to acceleratory forces.

- The Human Centrifuge: consists of an arm which rotates about a central point like a spoke on a wagon wheel. Usually an operator sits at what corresponds to the hub of the wheel. A modified aircraft cockpit is mounted at the peripheral end of the "spoke". The subject sits in the cockpit and is rotated during the experiment. The human centrifuge is elaborately equipped with recording devices so that necessary data can be obtained. Some of the factors which are measured are: number of G's applied, duration, electrocardiogram, heart rate, respiratory rate, loss of peripheral vision, loss of central vision (black-out) and unconsciousness. The record which is obtained shows all data on a single sheet of paper, along with calibrations, at 0.5 second intervals, for ease of interpreting and comparing, simultaneously, one reaction with another.

- The Accelerometer: consists of a fully movable weight which stretches a spring inside a cylinder. The position which the weight assumes through the force of gravity is marked as 1 G. By using multiples of the weight, which is attached to the spring, the scale is marked off in G units. If this instrument is suddenly moved or rotated, the force stretches the spring and the accelerometer measures the acceleration directly in G units. Due to inertia, the weight moves in a direction opposite to that of the force.

- The Drop Tower: is specifically designed to be 45 feet high. It has a maximum specimen size of 6X6 feet. The tower is designed for a maximum weight loading of 40,000 pounds. The carriage and specimen is not to exceed 1,000 pounds which would give a maximum of 40,000 pounds under a 40G loading. The test platform has a velocity of 42 feet per second.

In any experiment on acceleration forces, a limited number of variables will be under investigation. In order to obtain comparability between experiments, it is desirable that such non-experimental variables be set at standard values. The values to be included are: the amount of force input required for the experiment to be constant for all tests; the drop height as an integral portion of the force input, requiring, a given height and hydraulic pressure to produce the desired G's and the time duration or pulse for G application must be constant for all tests. This is also known as exposure time.

There is, at present, a diversity in the experimental techniques used in research on acceleration forces. This not only requires that each experimenter reports a detailed description of his testing procedure, but makes valid comparisons with physiological values extremely difficult and in most cases virtually impossible. The use of a smaller number of proven measuring techniques would aid greatly in systematizing the data on accelerative forces.

Although it is agreed that such standardization of techniques and data would be desirable, there are, at present, insufficient data about the possible methods to justify a choice among them. Experimentors in this field are, therefore, encouraged to carry out methodical studies, and also to present all data which might aid in evaluating their experimental technique and data. It is hoped that in the future some standardization of experimental techniques as well as acceleration tolerances, can be achieved in this field. Basically, these techniques would include:

- Adequate sample size
- Replication of conditions
- Measure of dispersion around critical tendency.

OBSERVATIONS AND RESULTS

The data points obtained from the literature together with those obtained from in-house studies, which covered a period of time from 1946 to present, were plotted. The data points were designated as type, and plotted against time and in relation to rate of onset. The symbology on Figures 1,2,3, and 4 is self-explanatory.

A computer program was then specified to perform a Polynomial Regression Analysis for first and second degree polynomials, in order to determine the "best-fit" curve for the data points plotted.

Figures 1, 2, 3, and 4 present the many data points plotted and the "best-fit" curve based on the computer program.

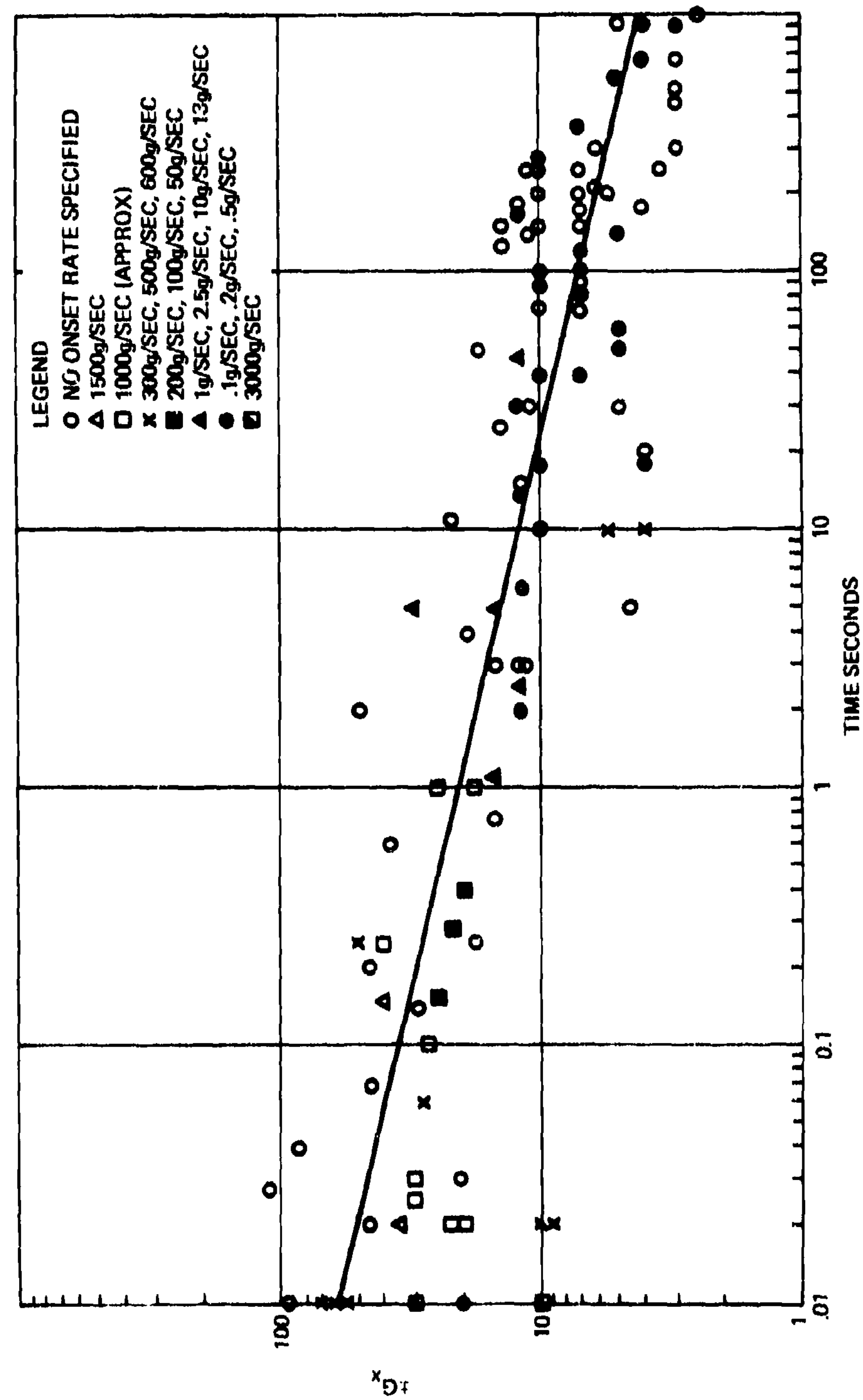


Figure 1 Transverse (ACCTOL-1) Data Points/Best Fit No-Injury Gee Tolerance

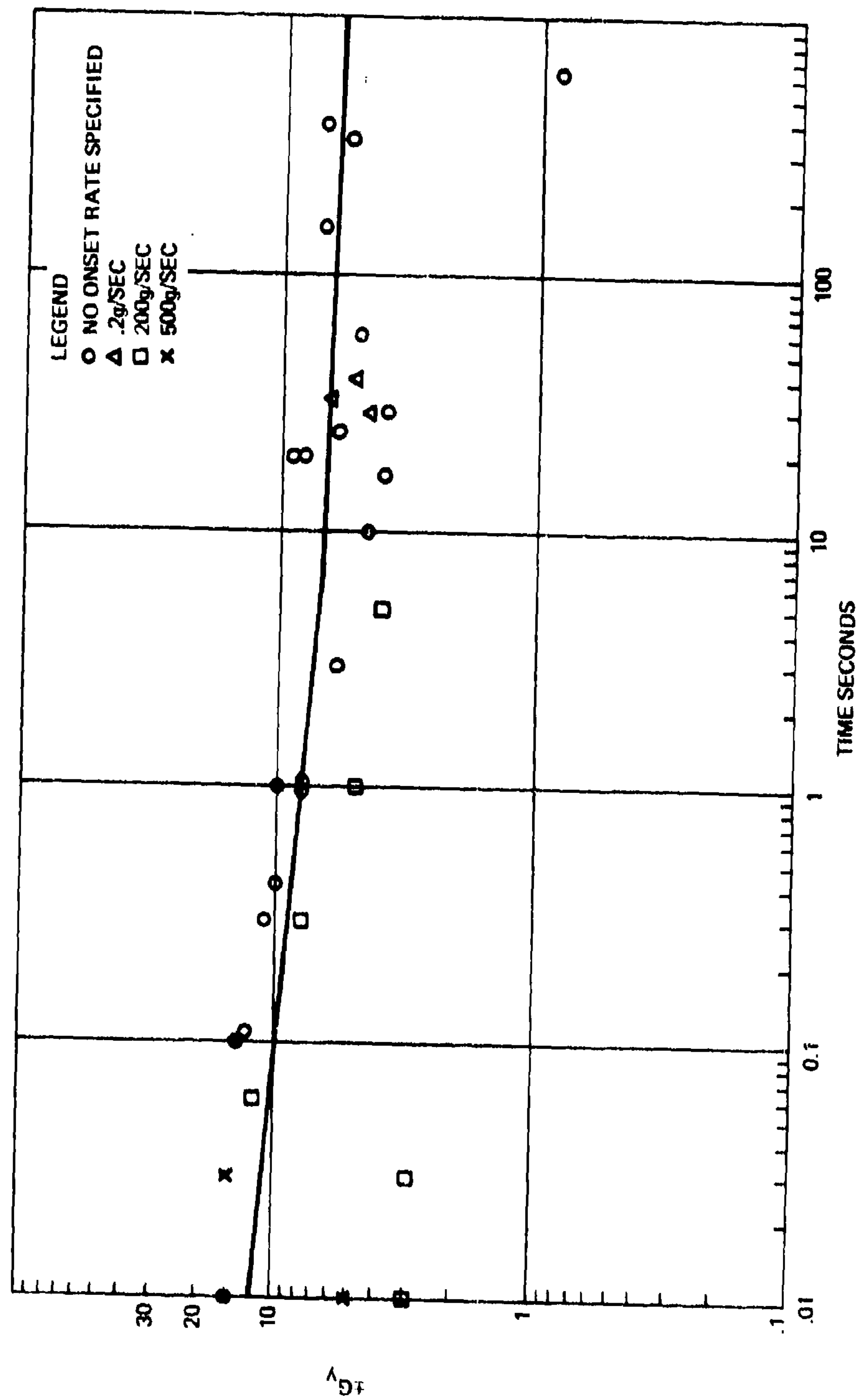


Figure 2 Lateral (ACCTOL-2) Data Points/Best Fit No-Injury Gee Tolerance

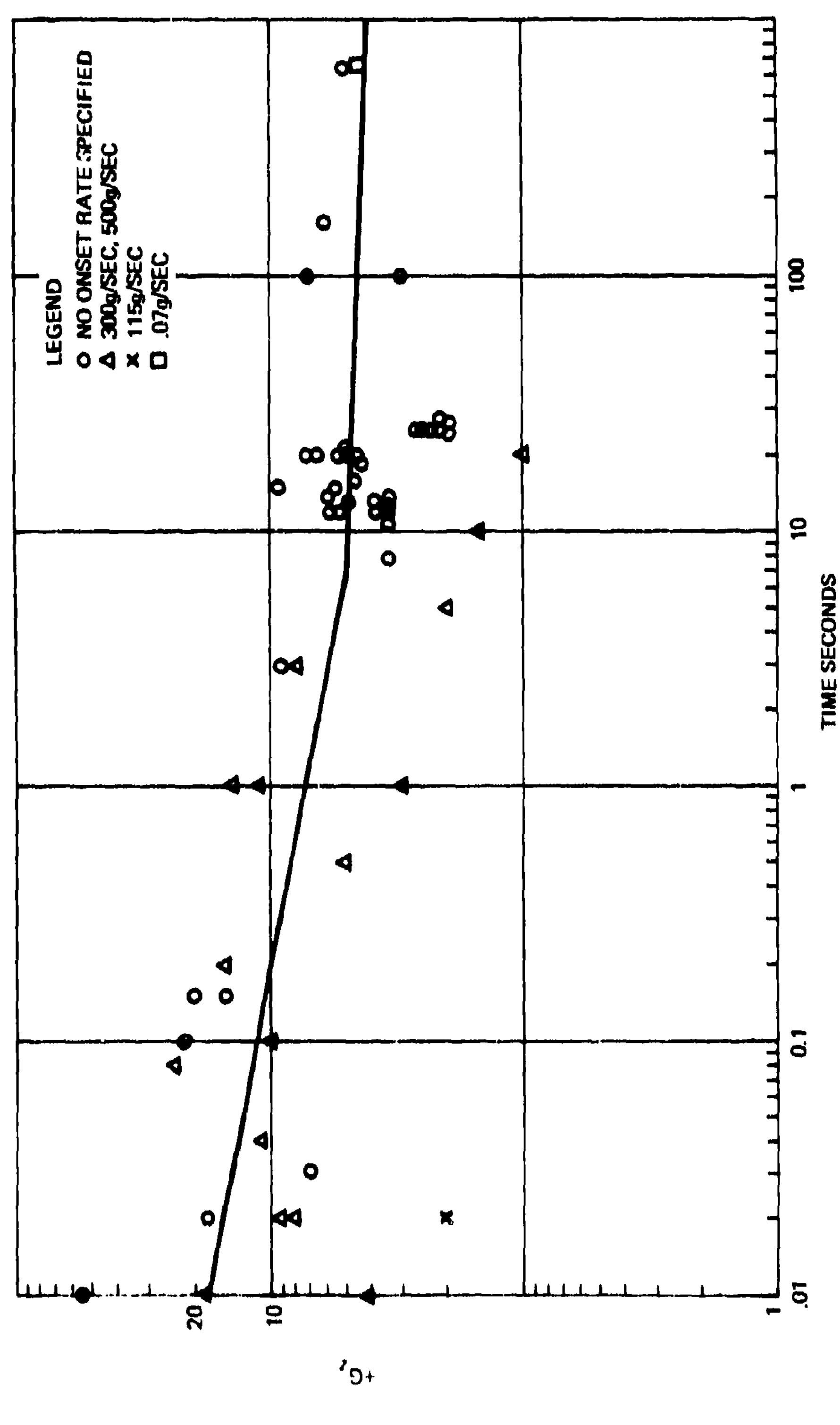


Figure 3 Positive Vertical (ACCTOL-3) Data Points/Best Fit No-Injury Gee Tolerance

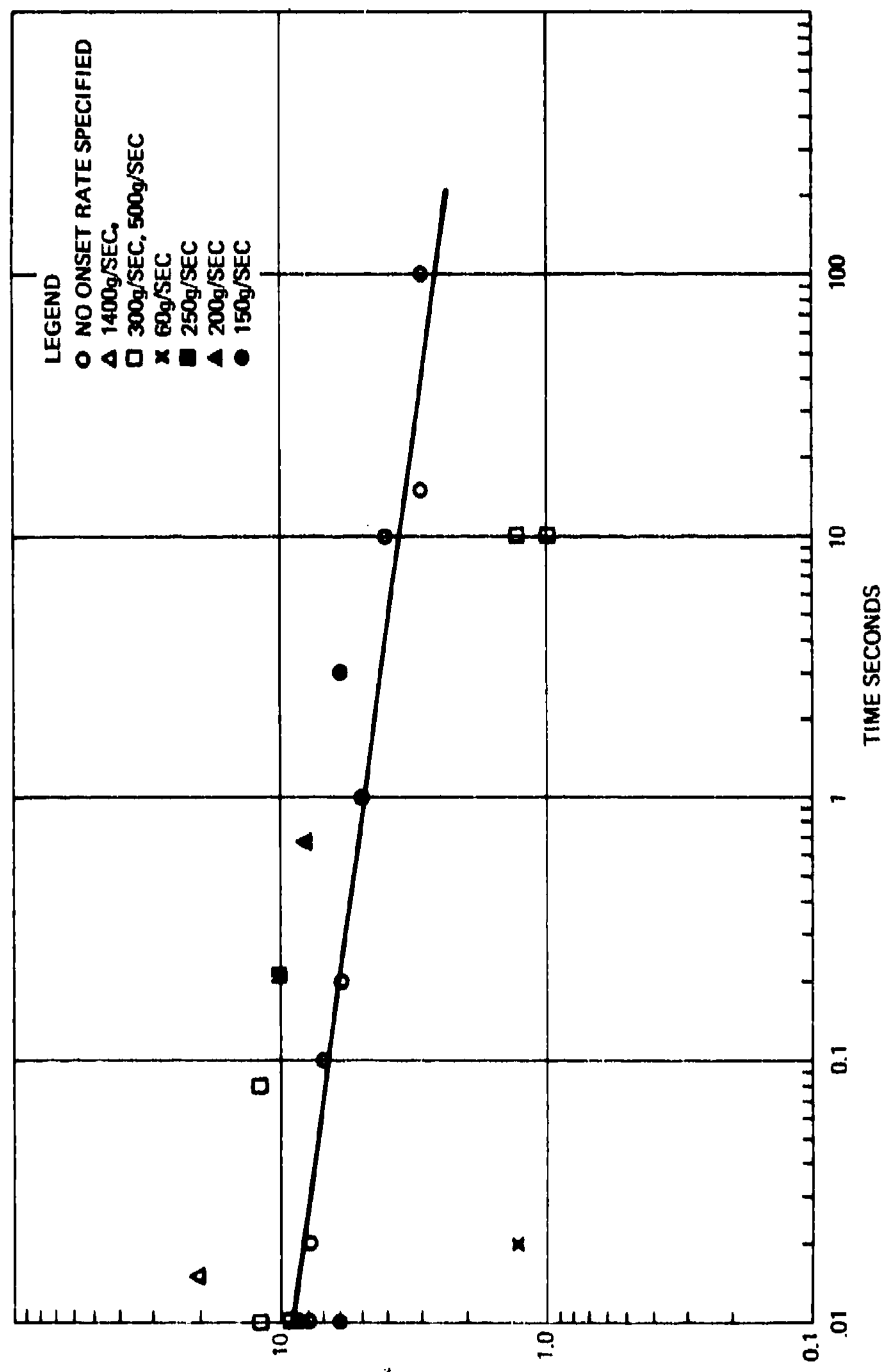


Figure 4 Negative Vertical (ACCTOL-4) Data Points/Best Fit No-Injury Gee Tolerance

APPENDIX B

PHYSIOLOGICAL ASPECTS OF WIND DRAG DECELERATION

The following remarks are intended to provide background information about physiological aspects of aircraft ejection. This report deals with wind blast deceleration.

An ejection seat leaves the vehicle cockpit at a forward speed equal to that of the aircraft. Entrance into the stationary air of the slipstream results in extremely rapid deceleration due to wind drag. The levels and characteristics of this deceleration (assuming a stable system) depends on:

- Air density
- Equivalent airspeed
- Combined mass of man and seat
- The effective cross-sectional area exposed, and
- The drag coefficient of man and seat.

Current knowledge of human tolerance to decelerative forces is based primarily on interpretation of results from rocket sleds and special restraint systems or investigations of accidents involving impact or unusual high-g ejections from high - performance aircraft.

Wind-drag deceleration poses one of the most formidable problems in high speed/high altitude escape. This is because of the increased probability of a fatality resulting from the unusually long duration of high-g forces. Indeed, the individual may be required to withstand an extremely high-g load for 10 or 20 times as long as he would as a result of ordinary crash deceleration. Duration of g-force has been emphasized in evaluation of the time-force injury spectrum. Tissue damage under these conditions is produced very rapidly as a result of hydraulic displacement of body fluids. The high-g hydraulic effect occurs subsequent to a latent period of 0.2 seconds; blood vessels rupture and cell membranes are damaged. No blood shifts occur when exposure is less than 1.0 second, although localized pressures and displacement of tissues can result in definite pathology.

Selection of reasonable design criteria when deceleration is a consideration, is complicated by the many factors that interact to determine human tolerances. The list includes:

- Direction of application of input
- Magnitude of input
- Duration of input
- Rate of onset
- Orientation of the body, and
- Characteristics of the restraint system.

If an ejection seat leaves an aircraft at 90° to the long-axis of the vehicle, the man will be exposed to on-axis g-loads in the transverse plane ($\pm G_X$). Studies of human tolerance in the transverse plane have been made with a short-track deceleration device that can produce loads ranging from 15 to 25g with a rate of onset ranging from 400 to 1000 G/second. Subjects participating in these experiments were uninjured in the physical sense but did suffer certain transient symptoms of physiological changes as outlined below:

- Shock: Blood pressure dropped subsequent to 15-20g ($\pm G_X$) runs with 500 G/sec rate of onset.
- Bradycardia: There was a slight slowing of heart rate (bradycardia) following a 15g peak. This response is related to activity of the vagus nerve. Greater slowing of heart rate occurred with increased decelerative g-loads.
- Transient Neurological Changes: Application of 20g peak (400-800 G/sec. rates of onset) causes the subject to appear to be stunned for 10 to 15 seconds. Also the wave patterns are abnormally slow (measured by an electroencephalogram) for several minutes following 25g at 1000 G/second rate of onset. Additional transient neurological changes include:
  - increased muscle tone
  - euphoria
  - loquacity
  - hand tremor
  - decreased coordination, and
  - gross involuntary movements of the head, arms, and trunk.

- Changes in Blood Platelets: Blood platelets are reduced about one hour subsequent to decelerations of 20g with 400 or 800 G/second rates of onset.
- Stress Reactions: There are changes in adrenal gland activity and blood chemistry.

Rocket sled studies have been used to evaluate human tolerance to decelerative forces in the transverse ($\pm G_x$) on-axis position. "Reversible incapacitation" was the criterion for selection of acceptable loads. This criterion is somewhat lost because incapacitation could be prolonged and thus might not be compatible with survival in the case of high "Q"/high altitude ejection. The tolerance limits given below must be considered therefore, as possibly too high:

- Rate of change deceleration limit is 1500 G/second at 40g for a duration of 0.16 seconds, or less
- Magnitude of force limit is 50g attained at 500 G/second rate of onset with a deviation of 0.20 seconds, or less
- Duration limit is 1 second for forces averaging 25g or more at 500 G/second.

Some workers have used 35g as the maximum allowable peak for linear deceleration. This design criterion takes into account a wide variety of variables including body attitude, effectiveness of restraints, seat stability, and the fact that a man should not be incapacitated following ejection from a vehicle. The sign value of 35g does not take into account two other important parameters -- rate of onset and duration of forces. The interactions of these two factors are summarized graphically in Figures 1 and 2.

Figure 1 shows a time-g curve that relates acceleration, rate of onset, and duration of forces in the absence of considerations such as speed and altitude. It can be seen clearly that when duration is longer than 0.1 seconds, tolerance to g-loads ($\pm G_x$) is greatly reduced. The "safe zone" shown requires a rate of onset of no more than 1000 G/sec. Figure 1 points up the serious problems caused by wind drag decelerations at high speed and high altitude. The problem is further underscored by the data summarized in Figure 2. As ejection altitude is increased, the duration of decelerative forces also is increased. This is because increased altitude, for any given speed, causes a greater kinetic energy for the ejected man and seat. Kinetic energy is a function of the square of true air speed (actual velocity). Therefore, at 40,000 feet the kinetic energy is increased to three times what it is at sea level for a given air speed. The increased kinetic energy is dissipated as a function of time in the less dense atmosphere at 40,000 feet. As can be seen in Figure 2, it would take about twice as long for decelerative g-loads to decrease from 35g to 10g at 40,000 feet as it would take at sea level. The formula that expresses the realtionships between duration of g-loads, air density, and altitude, is:

$$Th \cong \frac{Tsl}{\sqrt{P/P_o}}$$

- duration of g-loads at flight altitude = Th
- duration of g-loads at sea level = Tsl
- density of air at flight altitude = P
- density of air at sea level = P_o

As the formula shows, the duration of g-loads at flight altitude as compared to that at sea level is essentially proportional to the inverse of the square root of the ratio of air densities. It is obvious that duration of decelerative g-loads could be a serious problem for open ejection seat systems that must meet higher speed and altitude requirements that are presently specified.

Mach number, altitude, and indicated (calibrated) air speed are interrelated as shown in Figure 3. As can be seen in this figure, the peak decelerative g-load at Mach 1 at sea level is equal to the peak load at Mach 2 at 38,000 feet.

When projected data on drag coefficient, weight of the occupied seat, and exposed frontal area of a high "Q"/high altitude seat are available, it will be possible to calculate the characteristics of the g-loads. Until then, the relationships summarized in Figure 3 can be used as an indication of the forces to be anticipated. Judging from this figure it seems likely that the loads will be considerable.

An important consideration that must be known in order to determine the drag coefficient of a high "Q"/high altitude seat, is that of attitude. If the seat is tilted aft, as has been suggested, the occupant will take the decelerative g-load at an off-axis angle. This factor complicates the problem, from the physiological point-of-view. Unfortunately, few data on human tolerance to off-axis deceleration are available. Most of the studies of this subject have been in conjunction with NASA programs such as Apollo and these have utilized restraint systems, angles, and g-load patterns related to space flight trajectories.

The most pertinent data were obtained by means of a linear decelerating device that could be adjusted for variable axes of impact. The tests were run at measured g-levels ranging from 5.5 to 30.7 with a rate of onset varied from as low as 300 to as high as 25,000 G/second. The results of these experiments that are relevant to a high "Q"/high altitude system are summarized in Figure 4 and Table 1.

In 14 individual tests with a subject in a 45° backward pitch, there were 5 "complaint tests" during which the g-loads were too high for the test subjects. Application of g-loads ranging from 5.9 to 25.0 produced the following subjective symptomatology.

- Muscle spasms and strains of the neck and back; delayed onset and lasting for several days
- Chest pain; incidence at impact but of brief duration
- Shortness of breath; incidence at impact but of brief duration
- Muscle spasms and pain in the lower extremities; delayed onset and lasting for several days
- Stunning and disorientation; incidence at impact but of brief duration.

By way of comparison, when subjects were placed at a pitch of 35° with a yaw of 30°, 6 of 12 tests involved complaints in the g-load range of 18.5 to 24.5. The symptoms were essentially the same as those listed above. In other studies, subjects have withstood 25g in a 45° pitch without complaint. However, backward pitch of 45° clearly reduces human tolerance to g-loads in comparison to $\pm G_x$ axes. The degree to which tolerances is reduced is unknown, however, and therefore the 35g design criteria load might be too high when the loads will be applied to the subject when he is pitched backward 45°.

Studies of off-axis tolerance to g-loads serve to underscore the need for a contoured couch and good restraint system. For example, in one experiment, in which a test subject was pitched backward at 45° and subjected to 25g at 900 G/second for 97.0 milliseconds, hyperflexion of the trunk caused persistent soft tissue injury in the region of the 6th, 7th, and 8th thoracic vertebrae. It was determined that loose restraints were responsible. In a similar restraint system, a non-human subject sustained a vertebral fracture and recuperable internal injuries at 83g, 10,000 G/second.

Overall, it is likely that 45° will prove to be the maximum backward pitch acceptable for high "Q"/high altitude escape. Greater pitch (>45°) would place the subject in a position that would be similar to taking the g-loads longitudinally. Human tolerance in the (± G_z) axes is less than it is in the transverse (± G_x) or slightly pitched, off-axis, position.

SUMMARY

- Wind drag deceleration is a serious problem in open seat ejection
- Limits for transverse deceleration resulting in reversible incapacitation are:
  - rate of change deceleration limit is 1500 G/second at 40g for 0.16 second (or less)
  - magnitude of force is limited to 50g at 500 G/second with a duration of 0.20 second (or less)
  - duration limit is 1 second for forces averaging 25g or more at 500 G/second
- The present design limit without incapacitation in the transverse axis is 35g.
- High altitude deceleration results in greater duration of g-loads, which is a major problem because of the hydraulic effects on the body.
- Human tolerance to decelerative g-loads is reduced slightly by backward pitching of up to 45^{o}.
- Backward pitch probably should not exceed 45^{o}.

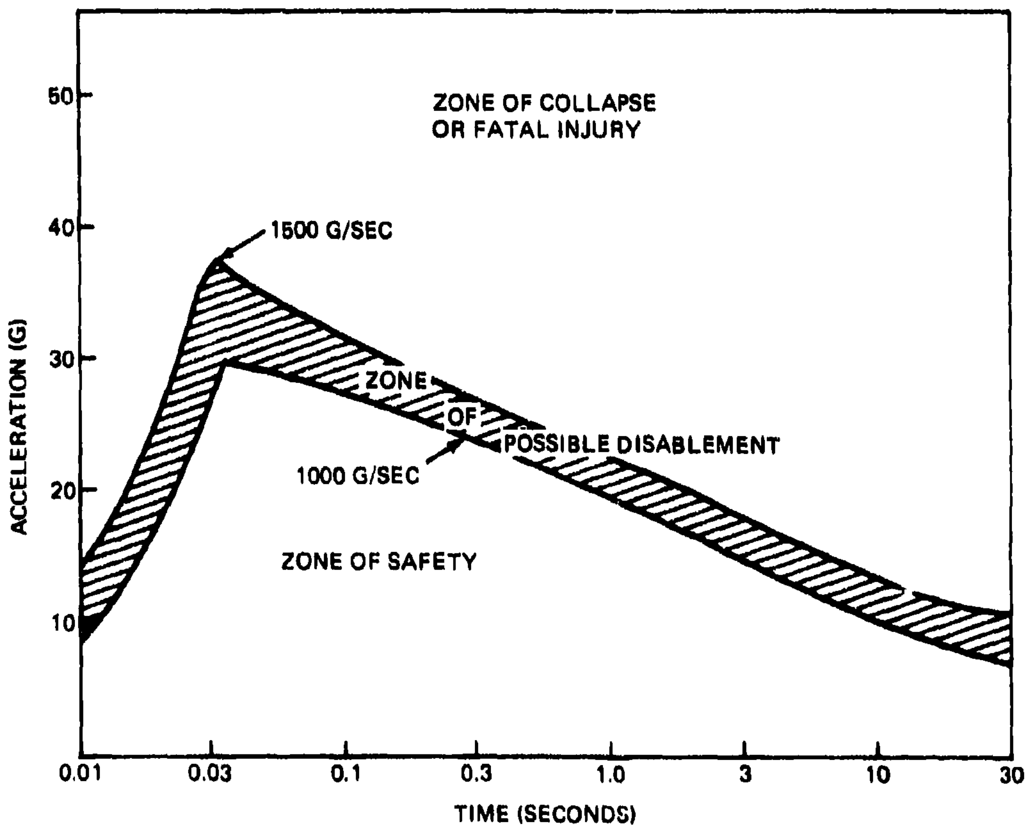


Figure 1 Limits of Human Tolerance to Wind Drag Deceleration.

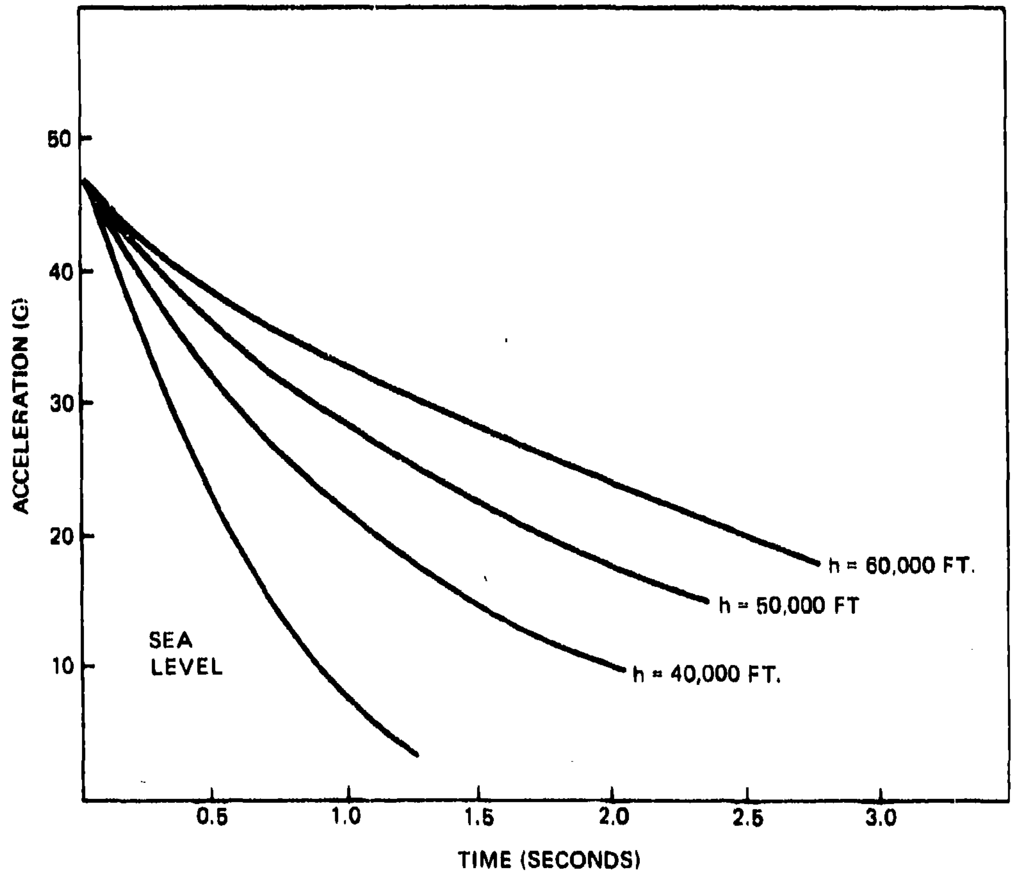


Figure 2 Duration of Decceleration Time as a Function of Altitude

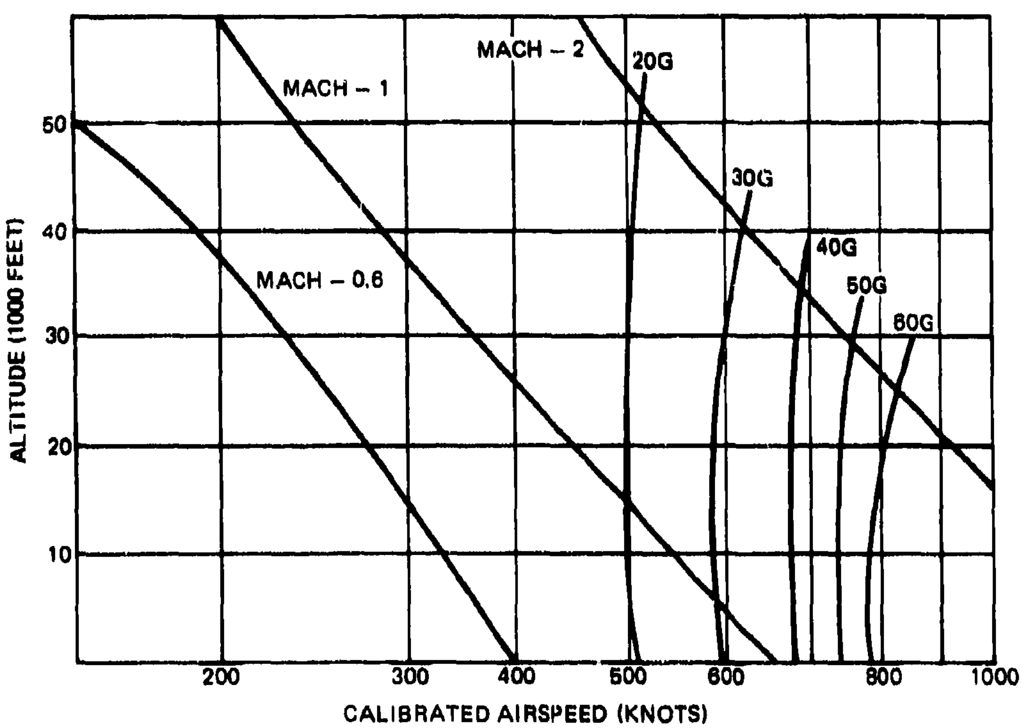


Figure 3 Level of G-Load as a Function of Calibrated Airspeed, Altitude, and Mach Number.

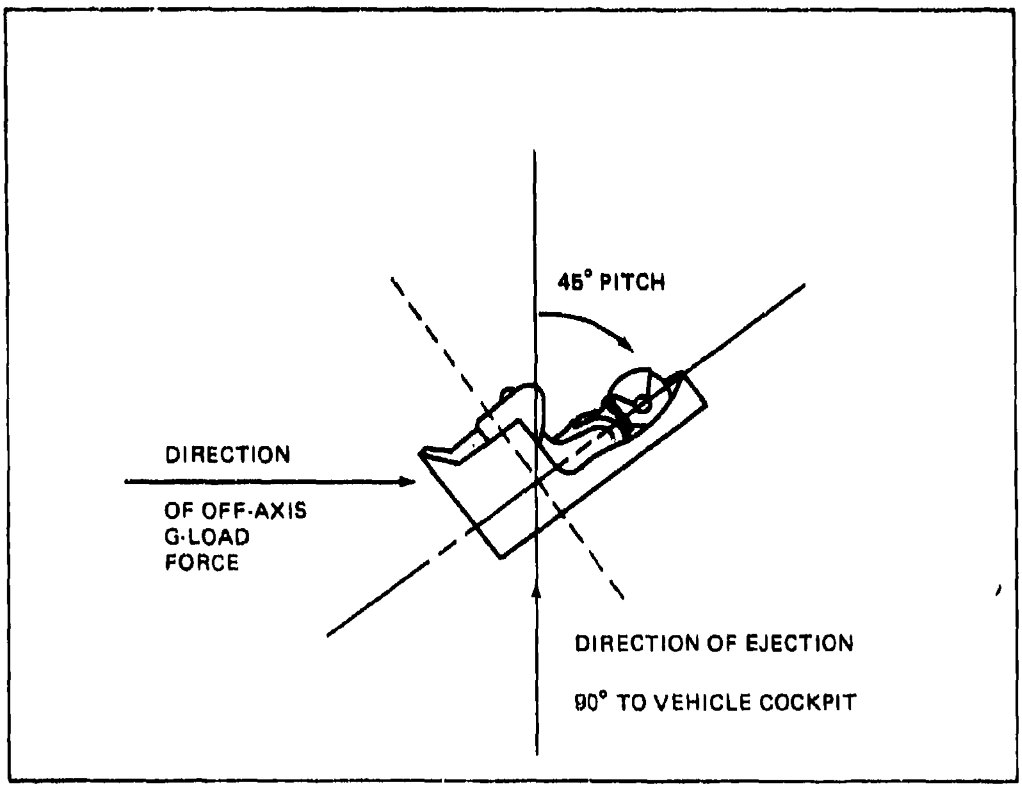


Figure 4 Orientation of Seat and Subject Relative to Decelerative Forces (0 roll, 45 Pitch, 0 Yaw).

Table 1 Comparisons of Human Tolerance to Decelerative Forces at Various Orientations.

POSITION			COMPLAINT
ROLL	PITCH	YAW	G RANGE
000	045	000	5.9 – 25.0
000	035	030	18.5 – 24.5
000	085	180	9.8
000	085	320	15.7 – 17.8

APPENDIX C

REVIEW OF THE LITERATURE

RE: – WIND BLAST EFFECTS AND THERMAL EFFECTS DURING HIGH SPEED OPEN SEAT EJECTION

BLAST EFFECTS

We cannot ignore the possibility of a classic blast injury from abrupt onset of wind blast pressure. Injuries resulting from the type of blast wave produced under the conditions which make escape feasible within limitations imposed by other parameters, such as wind drag acceleration, are not comparable to those of high explosive blast. Shock phenomena will be minimized due to the fact that pressures will not be sufficiently high. The onset of the dynamic pressure is several orders of magnitude slower than the onset of pressure resulting from explosions. The literature does not report any true blast injuries produced in actual supersonic escape nor in experimental rocket sled studies. In these studies, animals have been subjected to abrupt wind blast forces at velocities in excess of Mach 1.5 at sea level. Severe flutter and tear injury was prevented by protecting the animals with a wind proof helmet. German wind tunnel experiments during World War II demonstrated the hazards of facial injury. Exposure of the bare face to wind blast in excess of 400 knots for several seconds, produced minor injuries of the eyelids, nostrils, lips and ears. Human experiments in the United States resulted in no injury attributable to wind blast per se at 562 knots to a protected face. An uncovered or unprotected face also presents the hazard of inflation of the stomach and possible excessive lung pressure.

Stomach inflation of the human during supersonic escape without full face mask protection has been reported. These effects have also been produced in animals on the rocket sled. No lung injury has been reported to have resulted from wind blast effects. It has been suggested that additional studies can be conducted to determine if blast injury can be produced at technically feasible flight speeds. If such injury can occur, this will establish an absolute requirement for protection of the body with a rigid shield such as the escape capsule or a similar device. The factor of wind-drag deceleration in open seat ejection seats will most likely affect the escape velocity, and the effects of blast injury.

Injuries to the upper extremities have occurred in testing the downward ejection seat at speeds below 400 knots (IAS), giving evidence of the dangers involved.

Wind blast flailing has been responsible for lower extremity injuries to British and French flyers. Wind blast, causing premature deployment of parachutes has been responsible for fatal occurrences. It becomes apparent that effective means of securing protective equipment and the extremities against the forces of supersonic wind blast are required. This may be difficult to achieve without undue interference with aircrew performance. This is one of the many factors which may ultimately force abandonment of the open seat escape system in supersonic aircraft.

Wind-drag deceleration is perhaps the most formidable of all factors to be dealt with in high speed escape. The abrupt linear deceleration caused by the air-loads imposed on the ejected seat-man mass as it enters the air stream is a crash force. The lethal potentialities of wind-drag deceleration of a given magnitude are magnified beyond those of ordinary crash decelerations in that the duration of the high g forces may be in the order of 10 to 20 times as long. The element of instability during deceleration, resulting in tumbling and spinning, produces a very complex pattern of mechanical forces on the body.

Studies have emphasized the importance of g force duration at relatively high levels. Experimental definition and evaluation of the time force acceleration injury spectrum in the area between impact forces and centrifuge type hydro-dynamic circulatory effects has demonstrated that tissue damage is produced very rapidly as a result of hydraulic displacement of body fluids.

Critical problems are evident in the use of conventional ejection seats for escape in the upper range of speed and altitude capabilities of present day aircraft which are already well above 600 knots indicated air speed and 50,000 feet altitude.

Because the wind-drag deceleration problem in present configuration open seat ejection systems has been indicated as being serious, some proposed methods, as approaches to the solution of this problem, include the following:

(1) Drag chutes to slow the aircraft down prior to ejection.

(2) Rocket thrust augmentation on the seat in the direction of flight to counter the deceleration forces.

(3) Reduce the effective frontal drag by streamlining and increasing the seat weight to result in a lower drag/weight ratio.

(4) Seat stabilization in an acceptable attitude.

THERMAL STRESS OF EJECTION

Thermal problems, in escape from aircraft at high altitude, could either be due to cold or high temperature. Ambient temperature effects of high altitude can result in serious frostbite unless all parts of the body are adequately covered with protective clothing. High temperature problems related to the aerodynamic heating of high speed have not yet been encountered under actual escape conditions. Aerodynamic heating is very great at high Mach numbers, a general rule of thumb being that the temperature rise in Fahrenheit will be approximately 75 times the square of the Mach number; thus, a speed of Mach 10 would yield a temperature of 7500°F.

Information is only available for low altitude, high speed thermal exposure. High speed sled wind blast runs at Mach 1.7 have resulted in severe third degree burns of exposed areas of large animals. Measured surface temperatures at Mach 1.7 vary between 300 and 320°F.

The explanation given for the severe burns produced by such momentary exposure (1 to 10 sec) to relatively moderate temperatures is that the total heat transfer must have been very great.

Studies have shown that third degree burns can be produced in 10 seconds at skin temperature of 140°F. Therefore, under conditions of wind blast exposure involving a combination of pressure on the skin surface and a flow of heated dense air, unusual thermal injury may occur.

Aerodynamic thermal stress may present a serious hazard, requiring an enclosed capsule for protection at extremely high speeds which may be attained at extreme altitude. It is possible to provide protective clothing to successfully protect animals against injuries produced at Mach 1.7 at sea level. This protection can also be adapted to the flyer. Flyers, however, have demonstrated a resistance to acceptance of protective gear which must be worn on the body, thereby compromising comfort and performance.

When all is said and done, the fact remains that further evaluation of this problem is required.

AIRLOADS BORNE BY THE BODY IN RELATION TO SPEED AND ALTITUDE

Altitude	Ram Pressure	Total Pressure to 4 Square Foot Drag Area of Man
feet	p.s.f.	pounds
50,000	150	632
40,000	288	1152
30,000	432	1728
20,000	692	2768
15,000	850	3400
10,000	1010	4040
5,000	1240	4960
Sea Level	1440	5760

Speed - MACH 0.9

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