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CATAPULT PERFORMANCE AND INTERFACE REQUIREMENTS FOR LAUNCH OF BQM-34 VEHICLES

Teledyne Ryan Aeronautical Company

Prepared for:

Sacramento Air Materiel Area

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10 June 1974

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FINAL REPORT CATAPULT PERFORMANCE AND INTERFACE REQUIREMENTS FOR LAUNCH OF BQM-34 VEHICLES

REPORT NO. TRA 29369-5

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Launch Boundary

Launch Criteria

Load Factors

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CONTENTS

1

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| SECTION | | PAGE |
|---------|---------------------------------|------|
| 1.0 | INTRODUCTION AND SUMMARY | 1-1 |
| 2.0 | TECHNICAL DISCUSSION | 2-1 |
| | 2.1 General | 2-1 |
| | 2.2 Aerodynamics | 2-7 |
| | 2.3 Propulsion | 2-7 |
| | 2.4 Mass Properties | 2-14 |
| | 2.5 Structures | 2-18 |
| | 2.6 Simulation | 2-41 |
| 3.0 | REFERENCES | 3-1 |
| APPEN | DIX - POTENTIAL HAZARD ANALYSIS | A_1 |

A THINK ALL ROOM

v

LIST OF FIGURES

FIGURE

1997 (A.S. 1997)

È.

| 2-1 | General Arrangement, BQM-34A, S, and Model 251 | 2-3 |
|------|--|------|
| 2-2 | General Arrangement, BQM-347, E, and T | 2-5 |
| 2-3 | BQM-34A J69-T-69 Engine Gross Thrust Ram Drag | |
| | and Fuel Flow Rate at 5, 000 Feet and Ambient | |
| | Temperature of 105°F | 2-8 |
| 2-4 | BQM-34F YJ69-T-406 Engine Gross Thrust Ram | |
| | Drag and Fuel Flow Rate at 5, 000 Feet and Ambient | |
| | Temperature of 105°F | 2-9 |
| 2-5 | BQM-34A J69-T-29 Engine, Gross Thrust and | |
| | Ram Drag. 100 Percent Rpn. Sea Level. Ambient | |
| | Temperature, -20°F | 2-10 |
| 2-6 | BQM-34F YJ69-T-406 Engine, Gross Thrust and | |
| | Ram Drag, 100 Percent Rrm, Sea Level, and | |
| | Ambient Air Temperature20°F | 2-11 |
| 2-7 | BQM-34A J69-T-29 Engine, Variation of Engine | |
| | Speed with Ambient Pressure and Temperature for | |
| | a Constant Thrust of 1030 Pounds at Mach No. = 0 | 2-12 |
| 2-8 | BQM-34F YJ69-T-406 Engine, Variation of | |
| | Engine Speed with Ambient Pressure and | |
| | Temperature for a Constant Thrust of 1005 Pounds | |
| | at Mach No. $= 0$ | 2-13 |
| 2-9 | Model BQM-34A Gross Weight and Horizontal | |
| | Center-of-Gravity Envelope | 2-15 |
| 2-10 | Model BQM-34A Gross Weight and Vertical | |
| | Center-of-Gravity Envelope | 2-17 |
| 2-11 | Model BQM-34F Gross Weight and Horizontal | |
| | Center-of-Gravity Envelope for Internal Fuel Only | 2-19 |
| 2-12 | Model BQM-34F Gross Weight and Vertical | |
| | Center-of-Gravity Envelope for Internal Fuel Only | 2-20 |
| 2-13 | Model BQM-34F Gross Weight and Horizontal | |
| | Center-of-Gravity Envelope for Internal and | |
| | External Fuel | 2-2] |
| 2-14 | Model BQM-34F Gross Weight and Vertical | |
| | Center-of-Gravity Envelope for Internal and | |
| | External Fuel | 2-22 |
| 2-15 | Sign Convention for Loads Analysis | 2-24 |

Although of Sources and Although and

LIST OF FIGURES (Continued)

FIGURE

a far her and the second second and the second s

PAGE

255.242.242.242.242.242

いたちないないとう

| 2-16 | BQM-34A (124) Longitudinal Aerodynamic Loads | |
|------|--|------|
| | vs. Airspeed | 2-25 |
| 2-17 | BQM-34F (166) Longitudinal Aerodynamic Loads | |
| | vs. Airspeed | 2-26 |
| 2-18 | BQM-34A (124) Lateral/Directional Aerodynamic | |
| | Loads for Side Ground Winds | 2-27 |
| 2-19 | BQM-34F (166) Lateral/Directional Aerodynamic | |
| | Loads for Side Ground Winds | 2-28 |
| 2-20 | BQM-34A (124) Forces vs. Airspeed for 2,000-P | |
| | Pound Net Thrust | 2-29 |
| 2-21 | BQM-34F (166) Forces vs. Airspeed for 2,000- | |
| | Pound Net Thrust | 2-30 |
| 2-22 | BQM-34A (124) Normal/Longitudinal Limit Load | |
| | Factor Envelope | 2-32 |
| 2-23 | BQM-34A (124) Normal/Lateral Limit Load Factor | |
| | Envelope | 2-33 |
| 2-24 | BQM-34F (166) Normal/Longitudinal Limit Load | |
| | Factor Envelope | 2-34 |
| 2-25 | BQM-34F (166) Normal 'Lateral Limit Load Factor | |
| | Envelope | 2-35 |
| 2-26 | BQM-34A (124) Catapult Launch With Airframe and | |
| | Thrust Asymmetries and 15-Knot Crosswind | 2-43 |
| 2-27 | BQM-34A (124) Catapult Launch Without Airframe | |
| | and Thrust Asymmetries and No Wind | 2-45 |
| 2-28 | BQM-34A (124) Catapult Launch With Airframe | |
| | and Thrust Asymmetries and 15-Knot Tailwind | 2-46 |
| 2-29 | Vehicle Launch, BQM-34A, $\theta_{CMD}=20$ Degrees, | |
| | $\theta_0 = 8$ Degrees, $V_0 = 465$ Ft./Sec., 15-Knot | |
| | Crosswind, Gross Weight = 3,000 Pounds | 2-47 |
| 2-30 | Vehicle Launch, BQM-34A, $\theta_{CMD} = 20$ Degrees, | |
| | $\theta_0 = 10$ Degrees, $V_0 = 465$ Ft./Sec., 15-Knot | |
| | Crosswind, Gross Weight = 3,000 Pounds | 2-48 |
| 2-31 | Vehicle Launch, BQM-34A, $\theta_{CMD} = 20$ Degrees, | |
| | $\theta_0 = 12$ Degrees, $V_0 = 465$ Ft./Sec., 15-Knot | |
| | Crosswind, Gross Weight = 3,000 Pounds | 2-49 |
| 2-32 | BQM-34A (124) Catapult Launch Trajectory | 2-51 |
| 2-33 | Effect of Pitch Command on Minimum Launch | |
| | Velocity (BQM-34F Catapult Launch) | 2-54 |
| 2-34 | Good Launch Boundary (BQM-34F Catapult Launch) | 2-55 |

LIST OF FIGURES (Continued)

| FIGURE | | PAGE |
|--------|---|------|
| 235 | BQM-34F Worst Case Dynamics, Launch Attitude = | |
| | 10 Degrees, Launch Velocity = 450 Ft./Sec. | 2-57 |
| 2-36 | BQM-34F Catapult Launch, Launch Attitude = 8 | |
| | Degrees, Launch Velocity = 450 Ft./Sec. | 2-58 |
| 2-37 | BQM-34F Catapuit Launch, Launch Attitude = 12 | |
| | Degrees, Launch Velocity = 450 Ft./Sec. | 2-59 |
| 2-38 | Worst Case Trajectory (BQM-34F Catapult Launch) | 2-60 |
| 2-39 | General Trend of Vehicle Weight on Velocity | |
| | Requirements (BQM-34F Catapult Launch) | 2-62 |
| 2-40 | Effect of Weight on Trajectory (BQM-34F | |
| | Catacult Launch | 2-63 |

1.8.2

2445

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1.0 INTRODUCTION AND SUMMARY

Thiz technical report is submitted in accordance with Sequence Number A002 of Form DD1423 under Air Force Contract Number F04606-73-A-0048/SC 18 to provide information for the design of a catapult launcher for the Teledyne Ryan BQM-34A and BQM-34F series of drcnes.

Information contained herein provides performance and vehicle interface data for an independent contractor to prepare cost estimates for the design and manufacture of a catapult for the aforementioned vehicles. Curves of engine data are provided for various temperature and pressure conditions. Aerodynamic loads for various pitch attitudes up to 250 LEAS are also included. Limit load factor envelopes and limit loads for the present ground launch fittings are also presented in this report.

Conclusions based on the results of a six-degree-of-freedom dynamic simulation study for a catapult launch of a BQM-34A with the LSI A/A37G-8 autopilot are given below. These results are based on a study of drone launch characteristics beginning at release from the catapult shuttle.

- a. Catapult launch of the assumed worst case configuration can be best achieved with rpm = 100 percent. $\theta = 10$ degrees, $\theta_{CMD} = 20$ degrees and $V_0 = 465$ feet per second.
- b. Lightweight vehicles (2,000 pounds) can be launched at speeds approaching 400 feet per second.
- c. In general, pitch attitude commands greater or less than 20 degrees require higher catapult velocities to launch the vehicle considered in the study.
- d. Horizontal distance required to achieve an altitude gain of 200 feet is inversely related to θ_{CMD} . The lower (smaller) the command, the longer the distance.
- e. Other vehicle configurations must be adequately analyzed to assure successful launch and to establish the most adequate pitch command for each case.

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Conclusions based on the results of a six-degree-of-freedom dynamic simulation study for a catapult launch of a BQM-34F with the LSI A/A37G-9 sutopilot are as follows:

- a. The vehicle should be launched at 10 degrees pitch attitude, and under worst case conditions, at least 450 feet per second catapult launch velocity and the engine running at 100 percent rpm.
- b. No autopilot changes are required. The present ground launch pitch attitude command of 25 degrees can be used.
- c. Further reductions in velocity can be made by decreasing vehicle weight or by an initial pitch rate.

The drone mechanical and electrical interface requirements, drone capabilities and characteristics and catapult performance requirements treated in this report apply to unmodified vehicles and presently used ground launch provisions. Accomplishment of the design of the catapult, adaptation of the drones for catapult launch, and development of the catapult launch operational procedures, should be regarded as an iterative process with the information presented herein providing the foundation for that effort. Structural interface loads and load reaction points, vehicle separation characteristics, launch trajectory, and effects of different vehicle weights and configuration are a function of the catapult design and require further consideration during the catapult design phase.

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2.0 TECHNICAL DISCUSSION

2.1 GENERAL

Two basic configurations have been analyzed during the contract study. These include:

- a. BQM-34A Standard BQM-34A target (Teledyne Ryan Model 124), with a 36-square-foot wing, weight and inertia data scaled up to 3,000 pounds and the addition of a drag increment to compensate for the 11-inch diameter CIR pods.
- b. BQM-34F Standard BQM-34F (Teledyne Ryan Model 166) target with the 6-inch Hayes IR pods, and weight and inertia data scaled to 3,000 pounds.

Additional information for other target vehicles is also included herein. Figure 2-1 is a general arrangement drawing (124V322) for the following configurations: BQM-34A, BQM-34S and the Teledyne Ryan Model 251. Figure 2-2 is a general arrangement drawing (166V4002) for the following configurations: BQM-34F, BQM-34E, and the BQM-34T.

Analyses were conducted based on the following conditions:

- a. Temperature, 105°F
- b. Altitude, 5,000 Feet

For the dynamics analysis of the worst case configurations, the maximum temperature at 5,000-foot altitude was reduced from 130°F to 105°F. This decision, although arbitrary, was made on the basis of anticipated percentage of occurrence so as not to impose unrealistic requirements on the catapult.

Throughout this report, assumptions and limitations will be specified and the conditions and configurations used will be described.

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2.2 AERODYNAMICS

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> The BQM-34A configuration described in Paragraph 2.1 specifies the addition of a drag increment for 11-inch diameter CIR wingtip pods. This increment was estimated by using the methods of Reference 1 to determine subsonic zero lift drag. Pod induced drag was derived using data from References 1 and 2. Interference drag was derived from Reference 3 and unpublished data.

The resulting drag coefficient increment is 0.0132 for two pods and is valid for all lift coefficients and Mach numbers consistent with launch calculations.

All aerodynamic data based on published information for the configurations described were supplied for six-degree-of-freedom simulation studies (Reference 4). Results are presented in Paragraph 2.6.

2.3 PROPULSION

The TCAE J69-T-29 installed engine performance for the BQM-34A and the TCAE YJ69-T-406 installed engine performance for the BQM-34F were estimated for minimum and maximum thrust conditions. The minimum thrust operational conditions were specified at an altitude of 5,000 feet, ambient temperature of 105° F, and an engine speed of 100 percent. The gross thrust, fuel flow rate, and ram drag for minimum thrust conditions are presented in Figures 2-3 and 2-4 for the BQM-34A and BQM-34F, respectively. Note that the gross thrust vector acts along the jet axis which is inclined downward with respect to the aircraft axis. This cc_responds to 15 degrees for the BQM-34A and 8-1/3 degrees for the BQM-34F. The ram drag vector acts along the flight path. This applies to Figures 2-3 through 2-6.

The maximum e.gine thrusts would occur at sea level -20° F ambient temperature and 100 percent engine speed conditions. The gross thrust and ram drag for maximum thrust conditions are presented in Figures 2-5 and 2-6 for the BQM-34A and BQM-34F, respectively.

The variation of engine speed (rpm) with ambient pressure and temperature was estimated for a constant static thrust of 1,030 peunds for the BQM-34A and 1,005 pounds for the BQM-34F. The results are presented in Figures 2-7 and 2-8 for the BQM-34A and BQM-34F, respectively. All catapult launches will be made at the rpm corresponding to the static engine thrust levels used in the dynamic analyses. These rpm values are determined from Figures 2-7 and 2-8. As an example for the use of both



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Figure 2-3. BQM-34A J69-T-69 Engine Gross Thrust Ram Drag and Fuel Flow Rate at 5,000 Feet and Ambient Temperature of 105 Degree F.

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Figure 2-4. BQM-34F YJ69-T-406 Engine Gross Thrust, Ram Drag and Fuel Flow Rate at 5,000 Feet and Ambient Temperature of 105 Degree F.

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800 609 RAM DRAG, LBS. 400 200 Note: Net Thrust = Gross Thrust - Ram Drag 3000 2800 2600 i GROSS THRUST, LBS. 2400 2200 2900 1800 1600 1400 L 0.3 MACH NUMBER 0.5 0.6 0.2 0.1 0.4

Figure 2-5. BQM-34A J69-T-29 Engine, Gross Thrust and Ram Drag, 100 Percent Rpm, Sea Level, Ambient Temperature, -20 Degree F.

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Figure 2-6. BQM-34F YJ69-T-406 Engine, Gross Thrust and Ram Drag, 100 Percent Rpm, Sea Level, and Ambient Air Temperature, -20 Degree F.





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BQM-34F YJ69-T-406 Enginc, Variation of Engine Speed with Ambient Pressure and Temperature for a Constant Thrust of 1005 Pounds at Mach No. = 0 Figure 2-8.



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Figures 2-7 and 2-8 for a catapult launch of a BQM-34A at an ambient pressure of 25.46 inches of mercury and an ambient air temperature of 40°F, the following procedure applies. From Figure 2-7, the intersection of the aforementioned pressure and temperature read an rpm of 93.4 percent. This corresponds to a static engine thrust level of 1.030 pounds.

Provisions must be made to ensure that the vehicles are protected against foreign object damage (FOD) while on the catapult during engine start and run-up, and during the ground launch sequences. In the past, such protection has been provided by a screened bellmouth auxiliary inlet for ground run-up. In addition, a retractable sugar scoop auxiliary inlet has been used on ground launchers free engine start and run-up to launch rpms. These auxiliary inlets originally were utilized to eliminate a mild surge condition in the 80 to 96 percent rpm range for the prototype BQM-34A vehicles. From recent experience and deliberate investigation, it appears that conditions causing the surge in the prototype vehicles no longer exist. Consequently, the use of either auxiliary bellmouth in conjunction with the catapult is not required. Protection against FOD still is a requirement unless it can be proven such protection is unnecessary.

2.4 MASS PROPERTIES

2.4.1 Basic BQM-34A Design Data

Original design conditions for the BQM-34A are presented below:

- a. Design Gross Weight = 2,500 Pounds
- b. Forward Center-of-Gravity Limit = 3% MAC (XF 86.3)
- c. Aft Center-of-Gravity Limit = 29.3% MAC (XF 95.08)

- d. Horizontal Reference Plane = $X_F 0.0$
- e. Vertical Reference Plane = $Z_F 0.0$
- f. Lateral Reference Plane = 100 Inches to Left of YF 0.0

2.4.1.1 BQM-34A Horizontal Center-of-Gravity Envelope

The forward center-of-gravity limit is a structural limitation based on a design gross weight of 2,500 pounds and an ultimate load factor of 6.55. This limit is used for the most forward center-of-gravity limitation on the center-of-gravity envelope curve (Figure 2-9).

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Figure 2-9. Model BQM-34A Gross Weight and Horizontal C. G. Envelope

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The aft center of gravity is an aerodynamic limit not to be exceeded during flight conditions. Due to the design features of the BQM-34A, the most aft center of gravity during flight occurs when 10 percent of the fuel is remaining. These data are used to derive the most aft center-ofgravity limitation on the center-of-gravity envelope curve of Figure 2-9 for gross weights with full fuel including growth to 3,000 pounds and minimum weight of 2,000 pounds.

Actual horizontal center-of-gravity data for several standard BQM-34A configurations are also shown in Figure 2-9.

2.4.1.2 BQM-34A Vertical Center-of-Gravity Envelope

There are no aerodynamic or structural limitations established for vertical center-of-gravity locations of the BQM-34A. The only existing limitations are based on maximum and minimum adjustments in RATO alignment hardware. These limitations were compared with actual vertical center-of-gravity data for the BQM-34A configurations and were found to be adequate and reasonable limits in all cases analyzed.

Actual vertical center-of-gravity data for several standard target configurations and two experimental configurations are also shown in Figure 2-10.

2.4.2 Basic BQM-34F Design Data

Original design conditions for the BQM-34F are presented below:

- a. Design Gross Weight = 2,500 Pounds
- b. Forward Center-of-Gravity Limit = 15° MAC (X_F 259.04)
- c. Aft Center-of-Gravity Limit Without Wingtip Stores = 27.5% MAC (X_F 264.92)
- d. Aft Center-of-Gravity Limit With Wingtip Stores (IR Pods)
 = 31.57 MAC (XF 266.80)

The BQM-34F can also be flown with or without the external fuel tank and each case is treated as a separate configuration due to weight and center-of-gravity differences.



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Figure 2-10. Model BQM-34A Gross Weight and Vertical C.G. Envelope

2.4.2.1 <u>BQM-34F</u>, Horizontal Center-of-Gravit; Envelope, Internal Fuel Only

The forward center-of-gravity limit is used as the most forward centerof-gravity limitation on the center-of-gravity envelope curve of Figure 2-11.

The aft center-of-gravity limit is with IR pods on and the most aft centerof-gravity condition for the BQM-34F is also at zero fuel weight. These data are used to derive the most aft conter-of-gravity limitation on the center-of-gravity envelope curve for a gross weight range of 1,700 pounds to 2,500 pounds (Figure 2-11).

The BQM-34F is a relatively new configuration and actual center-ofgravity data has been limited. However, the data available are also shown in the figure.

2.4.2.2 <u>BQM-34F Vertical Center-of-Gravity Envelope</u>, Internal Fuel Only

Maximum and minimum adjustments in RATO alignment hardware provide the only specified limitations on the vertical center of gravity for the BQM-34F. The limitations shown, however, are based on actual data.

Actual vertical center-of-gravity data for the BQM-34F are shown on the envelope curve of Figure 2-12.

2.4.2.3 Model BQM-34F Horizontal and Vertical Center-of-Gravity Envelopes With Internal and External Fuel

Data for the BQM-34F horizontal center-of-gravity envelope are derived on the same basis as used on the clean configuration, except the gross weight range used is from 2.130 pounds to 3,000 pounds due to the heavier weight. These are shown in Figures 2-13. Data for the vertical centerof-gravity envelope are shown in Figure 2-14.

2.5 STRUCTURES

This paragraph presents structural information concerning the BQM-34A and BQM-34F airframes which must be considered in the design and development of a catapult launcher for these target vehicles. Aerodynamic loads developed by the vehicles are presented as a function of a number of variables, including airspeed, side winds and attitude. The maximum loads that may be applied to the airframes at specified hard



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Figure 2-11. Model BQM-34F Gross Weight and Horizontal C.G. Envelope for Internal Fuel Only

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Figure 2-12. Model BQM-34F Gross Weight and Vertical C.G. Envelope for Internal Fuel Only

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Figure 2-13. Model BQM-34F Gross Weight and Horizontal C.G. Envelope for Internal and External Fuel

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Figure 2-14. Model BQM-34F Gross Weight and Vertical C.G. Envelope for Internal and External Fuel

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points are presented as are the maximum accelerations that may be imposed. The effects of jet engine thrust is also discussed.

Figure 2-15 shows the sign convention used for presenting loads and accelerations. Any deviations are clearly noted.

2.5.1 Aerodynamic and Engine Thrust Forces

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Aerodynamic forces on the targets and the forces generated by jet engine thrust are presented in Figures 2-16 through 2-21. In Figures 2-16 and 2-17, the longitudinal aerodynamic forces are shown for the BQM-34A and BQM-34F, respectively. The forces show the effects of the different pitch angles and two elevator positions as a function of airspeed. Linear interpolation may be used to determine aerodynamic forces for target pitch angles and elevator positions other than those shown. The airspeed may be considered the sum of the dolly ground speed and head or tail winds. As an example, consider a BQM-34A catapult launch at the iollowing conditions:

- a. Pressure altitude = 5,000 feet
- b. Temperature = $105^{\circ}F$
- c. Launch ground velocity required with 15-knot (25-fps) tail wind = 465 fps
- d. Elevators 100 percent trailing edge up
- e. Target pitch angle of 10 degrees

The airspeed is 440 fps which converts to 247 knots equivalent airspeed (KEAS). The following aerodynamic forces are obtained from Figure 2-16:

- a. L = 4,250 pounds vertical to rails
- b. D = 2,050 pounds parallel to rails
- c. $M_Y = 39,300$ inch-pounds

The lateral-directional aerodynamic forces due to a 15-knot side wind are shown in Figures 2-18 and 2-19. Figures 2-20 and 2-21 present forces due to net engine thrust levels of 2,000 pounds. and the structure of the balance of the second second construction of the second of the second s



- NOTES: 1. All quantities shown are positive. Positive forces, accelerations and load factors are up, aft and left.
 - 2. Use left hand rule for moments M_x and M_z
- 3. Lateral load factor (μ_y) and side force (Ly) are positive to left.
- 4. Positive accelerations produce positive load factors.
- 5. BQM-34A (124) 25% MAC FS 93.646, BLO, WL 20 BQM-34F (166) 25% MAC - FS 263.74, BLO, WL 57
- Subscript "G" ground axes, purallel and normal to launch rails. Subscript "B" - RPV body axes.

Figure 2-15. Sign Convention for Loads Analysis

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Figure 2-16. BQM-34A (124) Longitudinal Aerodynamic Loads vs. Airspeed

2-25


Figure 2-17. BQM-34F (166) Longitudinal Aerodynamic Loads vs. Airspeed

2-26

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Figure 2-18. BQM-34A (124) Lateral/Directional Aerodynamic Loads for Side Ground Winds

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NOTES:

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2) 3) SIDE WINDS OF 15 KTAS

LOADS ARE IN GROUND AXES

LOAD REFERENCE POINT IS 25% MAC, $Z_F^2 20$



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Figure 2-19. BQM-34F (166) Lateral/Directional Aerodynamic Loads for Side Ground Winds

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- 1) LOAD REFERENCE POINT IS 25% MAC, $Z_F^2 20$; GROUND AXES
- 2) LOADS ARE LIMIT
- 3) RATIO DIRECTLY TO OBTAIN FORCES FOR VALUES OF NET THRUST OTHER THAN 2000 LB.



Figure 2-20. BQM-34A (124) Forces vs. Airspeed for 2,000-Pounds Net Thrust

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1) LOAD REFERENCE POINT IS 25% MAC, Z_F^{57} ; GROUND AXES

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3) RATIO DIRECTLY TO OBTAIN FORCES FOR VALUES OF NET THRUST OTHER THAN 2000 LB.

Figure 2-21. BQM-34F (166) Forces vs. Airspeed for 2,000-Pound Net Thrust

Refer to Paragraph 2.3 for engine thrust data for various environment.: conditions. The forces of Figures 2-20 and 2-21 may be directly ratioed to any desired value of net engine thrust. All of the forces and moments of Figures 2-16 through 2-21 are limit loads and include no safety factors.

2.5.2 Airframes Structural Limitations

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Existing hard points and the airframe structure of the BQM-34A and BQM-34F vehicles were evaluated to determine allowable inertia load factors and interface loads during a catapult launch. It is assumed that no structural modifications are incorporated and that interface loads will be applied to existing hard points. Normal fuel pressurization at launch is considered. Inertia fuel pressure computations are based on the use of JP-5 fuel at standard conditions.

On the BQM-34A, the forward and aft fuel ank bulkheads are sensitive to fuel pressure resulting from longitudinal acceleration. The vertical members on the aft bulkhead at X_F 36.0 are critical under bending stress due to forward acting pressure loads. On the BQM-34F, the engine inlet duct is critical under collapsing external pressure due to fuel inertia loads combined with internal negative pressure due to airflow with the engine running. The forward end of the duct is critical from fuel pressures due to forward acting fuel pressure loads.

The maximum allowable limit load factors for the BQM-34A and BQM-34F targets are presented as envelopes in Figures 2-22 through 2-25. These values are the maximum allowable limit load factors to which the vehicles may be subjected. These limit values are consistent with an ultimate factor of safety of 1.50 between limit and ultimate. It should be noted that the load factor envelopes of Figures 2-22 through 2-25 are presented in the target body axis system.

During the catapult launch, contributions to the loads and accelerations experienced by the targets can be expected from the applied acceleration forces, engine thrust forces, aerodynamic forces due to forward airspeed and ground winds, and undulations in the tracks or rails of the catapult launcher. The most critical combination of these effects, and perhaps others, must not exceed the limit load factor envelopes of Figures 2-22 through 2-25. Accelerations calculated in the catapult launcher axis system must be transformed to the target body-axis system for comparison with the above figures. The following equations may be used for this purpose if the sign convention of Figure 2-15 is followed:

a.
$$n_z = n_z \cos \theta + n_x \sin \theta$$

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- 1) LOAD FACTORS ACT THROUGH TARGET CENTER-OF GRAVITY IN BODY AXIS, SEE FIG. 2-15.
- 2) SEE FIGURE 2-23 FOR LATERAL LOAD FACTOR TO BE COMBINED WITH EACH LETTERED POINT.



Figure 2-2%. BQM-34A (124) Normal/Longitudinal Limit Load Factor Envelope

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- 1) LOAD FACTORS ACT THROUGH TARGET CENTER-OF-GRAVITY IN BODY AXES AND IN DERECTION OF ACCELERATION
- 2) SEE FIGJRE 2-22 FOR LONGITUDINAL LOAD FACTOR TO BE COMBINED WITH EACH LETTERED POINT CONDITION.



Figure 2-23. BQM-34A (124) Normal/Lateral Limit Load Factor Envelope

- 1) LOAD FACTORS ACT THRU TARGET CENTER-OF-GRAVITY IN BODY AXES AND IN DIRECTION OF ACCULERATION
- 2) SEE FIGURE 2-25 FOR LATERAL LOAD FACTOR TO BE COMBINED WITH EACH LETTERED POINT



Figure 2-24. BQM-34F (166) Normal/Longitudinal Limit Load Factor E-velope



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Figure 2-25. BQM-34F (166) Normal/Lateral Limit Load Factor Envelope

b.
$$n_{x_B} = -n_z \sin \theta + n_z \cos \theta$$

Hold-back requirements for prelaunch engine run-up shall consider, in addition to engine thrust forces, ground winds from any direction. Engine thrusi forces are obtained from Figures 2-20 and 2-21. Longitudinal aerodynamic forces for 35-knot ground head or tail winds are obtained from Figures 2-16 or 2-17. For tail winds, multiply the forces shown for 35 KTAS by -1. Forces due to side winds, if applicable, can be obtained from Figures 2-18 and 2-19.

The existing structural hard points on the BQM-34A and BQM-34F targets have been evaluated for their structural load carrying capability. The hard points and their capabilities are discussed below. The total loading applied to all of the hard points should not, for any case, produce load factors in excess of those described above. The hard point loads are presented as limit loads and are the maximum loads that may be applied to the hard points. The limit loads are consistent with an ultimate factor of safety of 1.50 between limit and ultimate.

The existing BQM-34A and BQM-34F hard points are illustrated in the following sketches:



BQM-34A HARD POINT LOCATIONS

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BQM-34F HARD POINT LOCATIONS

2.5.3 BGM-34A Hard Points

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> Thrust fitting at $X_F = 144.28$, $Y_F = 0.0$, $Z_F = 6.96$. This fitting and its attachment were designed for introducing rocket motor thrust loads during ground launch. Stress analysis indicates that the fitting attachment to the fuselage is critical under axial loads with a downward component as shown in the sketch below. The launch fitting installation and fuselage structure is not critical under reasonable side loads and an arbitrary value is used. Limit allowable loads are shown in the following sketch. Loads may act independently or concurrently.



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Keel fitting at $X_F = 30.0$, $X_Y = 0.0$, $Z_F = -2.8$. The keel fitting was designed for loads in the vertical plane introduced during ground launch during rocket-motor thrust build-up. Loads are introduced through a steel spool which clamps the channel sides of the keel member. The failure mode under loads in the vertical plane is tension failure at the hole edge. The hole edge is critical in bending under side loads.

Allowable limit loads are illustrated below. Loads may act independently or concurrently.



Wing fittings at $X_F = 81.2$, $Y_F = \pm 15.0$, $Z_F = 17.06$. These fittings are attached to the lower surface of the wing and react longitudinal, lateral and vertical loads. The fitting is capable of 5,000-pound limit upward (i.e., compressive) vector load acting in a 45-degree cone about the vertical axis. The fitting capability for downward load is limited by fastener tension allowables. A design equation based on a load vector and fastener tension capability was derived and is illustrated on the following page. Due to attachment symmetry about the lateral axis, this equation is also valid for forward longitudinal loads.

2-38

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Thrust fitting at $X_F = 324.97$, $Y_F = 0.0$, $Z_F = 36.85$. This fitting and attachment was designed for rocket motor loads during ground launch. Stress analysis indicates that the fitting and attachment is critical under axial loads with a downward component as shown in the sketch on the following page. The fitting installation and fuselage structure are not critical under reasonable side loads and an arbitrary value is established. The following limit loads may act independently or concurrently.

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Fuselage support fittings at $X_F = 233.94$, $Y_F = -12.14$, $Z_F = 51.5$. Socket fittings machined in a boss in the frame at $X_F 233.5$ transmit ground handling and ground launch loads to the frame. The frame is not critical for in-plane (i.e., lateral) loads and arbitrary limit loads are established. Stress analysis for longitudinal loads at the fitting provides an allowable limit load of 2,600 pounds. Allowable limit loads are illustrated below. Loads may act independently or concurrently.



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2.6 SIMULATION

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2.6.1 BQM-34A Catapult Launch

The significant parameters affecting the catapult launch of a BQM-34A (Teledyne Ryan Model 124) with the LSI A/A37G-8 autopilot have been investigated using an EAI 8400 digital computer and a six-degree-of-freedom simulation representing an assumed worst case configuration. The worst case configuration consists of basic BQM-34A aerodynamic data with a drag increment of $\Delta C_D = 0.0132$ to account for two 11-inch diameter Hayes CIR pods. The weight used was 3,000 pounds (gross) with a center-of-gravity position at X_F 86.3 inches (3% MAC). The launch analysis was conducted at a pressure altitude of 5,000 feet and an ambient temperature of 105°F. Engine rpm was constant at 100 percent.

Aerodynamic derivatives and other characteristics for the simulation were obtained from Reference 4.

The analysis has resulted in establishing a minimum speed of 465 feet per second at which the above configuration can be successfully launched with worst case aerodynamic asymmetries and a 15-knot tail wind (15knot cross winds were found to be less restrictive). The study has also shown that a pitch attitude command of 20 degrees and an initial pitch attitude of 10 degrees give the most acceptable launch and climbout for the configuration studied.

A brief examination of several other weight and center-of-gravity combinations has indicated a requirement for further study of other configurations. Heavy weight, aft center-of-gravity configurations may require a reduction in the pitch attitude command.

The launch analysis and results are predicted on certain criteria used to define an acceptable launch. These criteria are as follows:

- a. Bank angle not to exceed ± 40 degrees.
- b. Control surface deflections not to be mechanically limited for more than three (3) seconds.
- c. Altitude rate always greater than zero.
- d. Velocity during launch and climbout sufficient to maintain steady-state angle of attack less than 10 degrees.

All of the criteria must be satisfied to qualify as an acceptable launch.

The vehicle configuration was an assumed worst case; that is, high weight, forward center of gravity, most adverse aerodynamic and thrust asymmetries are as shown below:

- a. Gross Weight = 3,000 Pounds
- b. Center of Gravity at XF 86.3
- c. Basic Model 124 aercdynamics with $\Delta C_D = 0.0132$ for the two Hayes CIR pods
- d. Aerodynamic Asymmetries:
 - (1) $\Delta C_n = 0.006$
 - (2) $\Delta C_{l} = 0.005$
 - (3) $\Delta C_{Y} = 0.011$
- e. Engine at 100 percent rpm
- f. Engine sideforce and yawing moment from 1 percent gross thrust applied at the tail pipe exit
- g. The BQM-34A FCS could not be significantly modified

The launch analysis was conducted at a pressure altitude of 5,000 feet and a temperature of 105°F. The effect of surface winds was also evaluated using 15 knots for cross and tail winds and 35 knots for head wind.

Since the catapult design is not known, ground effects and any initial interference effects with the catapult hardware could not be considered.

The information contained above was incorporated in a six-degree-offreedom program utilizing an EAI 8400 digital computer. This simulation was then used to determine the minimum speed for an acceptable launch for any given pitch attitude and pitch attitude command.

Results

The results of the simulation effort to evaluate the catapult launch characteristics of an assumed worst case BQM-34A are contained in Figures 2-26 through 2-31. Figure 2-26 presents the minimum launch speed requirements for the vehicle. Included in this figure are the effects of

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5000 FEET @ 105 DEGREE F GROSS WEIGHT = 3000 POUNDS, 100% RPM

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ASYMMETRIES: APPROXIMATE HORIZONTAL DISTANCE TO $\Delta H = 200$ PT. 1) 1% GROSS THRUST SIDEFORCE HOR. DIST. θ CMD & YAWING MOMENT (NEG. $\triangle Cn$) 10° 14,000 FT 2) $\Delta C_n = -.006$ 15° 9,000 FT 3) $\Delta C_y = +.011$ 20° 7,000 FT 25° 4,000 FT 4) $\triangle C_1 = -.006$



Figure 2-26. BQM-34A (124) Catapult Launch With Airframe and Thrust Asymmetries and 15-Knot Crosswind

crosswinds and initial pitch rate. Note that the airframe and thrust asymmetries are worst case values and have been added to produce the most adverse effect. In addition, the effect of 15-knot crosswinds was evaluated with its influence added to the asymmetries.

In Figure 2-26, it can be seen that in general as pitch attitude and pitch attitude command are increased, the allowable launch speed is reduced. A reversal of this trend is most apparent for $\theta_{CMD} = 10$ degrees, $\theta > 0$ degrees. This is due to a mismatch between the attitude and command resulting in a detrimental lounch transient. This transient must be overcome with a higher launch velocity. A pitch attitude command of 20 degrees permits the minimum launch velocity to be obtained. At a pitch command of 25 degrees, the vehicle asymmetries begin to dominate causing $\phi > 40$ degrees and requiring a higher speed for an acceptable launch. Note that no data with 15-knot tail winds are shown but that this may be simply obtained by adding 15 knots (25 fps) to the no-wind data.

Figure 2-27 shows the required launch speeds for the 3,000-pound vehicle without any asymmetries or winds. It is obvious from examining these first two figures that the vehicle asymmetries play a significant part in the launch dynamics as reflected by the increase in launch speed due to asymmetries. A cursory investigation into the vehicle launch characteristics at various centers of gravity and weights other than the assumed woist case has pointed up a need to carefully examine a range of vehicle configurations to find the best pitch attitude command for each. For example, configurations with an aft center of gravity may be more effectively launched with 3 pitch command lower than 20 degrees or perhaps even at a lower velocit. A lower pitch command for the worst case configuration would, however, require higher speeds and result in a slower climb rate. The effect of pitch attitude command on the distance required to climb 200 feet is shown in the upper right hand portion of Figures 2-26 and 2-27.

Figure 2-28 presents data extracted from Figure 2-26 with the addition of a 15-knot tail wind and the added variable of gross weight. Data are only presented for a pitch attitude command of 20 degrees since this was deemed the best for the assumed worst case configuration. The curve in Figure 2-28 for 3,000 pounds, which as stated includes the effect of a 15knot tail wind, was used to establish the minimum acceptable launch speed of 465 feet per second. Shown on the figure is the region considered to produce a satisfactory launch of the assumed worst case vehicle.

Figures 2-29, 2-30, and 2-31 present representative launches of the worst case vehicle at various pitch attitudes around the chosen value of 10 degrees

5000 FEET @ 105 DEGREE F GROSS WEIGHT = 3000 POUN D, 100% RPM

NOTE:

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1) NO AIRFRAME OR THRUST ASYMMETRIES

2) NO WINDS



Figure 2-27. BQM-34A (124) Catapult Launch Without Airframe and Thrust Asymmetries and No Wind



C.G. @ F.S. 86.3 INCHES ALT = 5,000 FEET TEMP = 105°F RPM = 100%

ASYMMETRIES



2) AERO: $\Delta C_n = -0.006$ $\Delta C_l = -0.006$ $\Delta C_v = 0.011$



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Figure 2-28. BQM-34A (124) Catapult Launch With Airframe and Thrust Asymmetries and 15-Knot Tailwind

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= 8 Degrees, V_o = 465 Ft./Sec., Vehi-zie Launch, BQM-34A, $\frac{9}{0}$ = 20 Degrees, θ_0 15-Knot Crosswind, Gross Weight = 3,000 Pounds Figure 2-29,





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Figure 2-31. Vehicle Launch, BQM-34A, $\theta_{cmd} = 20$ Degrees, $\theta_{o} = 12$ Degrees, $V_{o} = 465$ Ft./Sec., 15-Knot Crosswind, Gross Weight = 3,000 Pounds

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with the pitch command at 20 degrees. A pitch attitude of 10 degrees ± 1 is considered to produce the best compromise between roll, initial rate of climb, longitudinal transient and control surface positions.

Figure 2-32 presents the launch climbout trajectory of the vehicle with a 15-knot tail wind. This represents the climbout requiring the most horizontal distance to gain an altitude of 200 feet. As noted previously, lower pitch commands will require more distance for the same altitude gain.

Conclusions

The conclusions of the assumed worst case configuration are as follows:

- a. Catapult launch of the assumed worst case configuration can be best achieved with rpm = $10\hat{\sigma}$ percent, $\theta = 10$ degrees, $\theta_{CMD} = 20$ degrees and $V_0 = 465$ feet per second.
- b. Lightweight vehicles (2,000 pounds) can be launched at speeds approaching 400 feet per second.
- c. In general, pitch attitude commands greater or less than 20 degrees require higher catapult velocities to launch the vehicle considered in the study.
- d. Horizontal distance required to achieve an altitude gain of 200 feet is inversely related to θ_{CMD} . The lower (smaller) the command, the longer the distance.
- e. Other vehicle configurations must be adequately analyzed to assure successful launch and to establish the most adequate pitch command for each case.

2.6.2 BQM-34F Catapult Launch

The purpose of the catapult launch analysis was to determine technical parameters for a preliminary target vehicle/catapult interface specification. The basic flight dynamics objective was to investigate and determine the initial pitch attitude and minimum launch velocity to satisfy an assumed worst case configuration and condition. To accomplish this objective, a six-degree-of-freedom digital flight simulation computer program was developed to represent the vehicle airframe dynamics, gyro dynamics, autopilot logic and circuitry including the transfer functions of the components, and the engine performance characteristics as the vehicle leaves the catapult. The basic simulation program is described in Reference 5



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Figure 2-32. BQM-34A (124) Catapult Launch Trajectory

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and the general arrangement of the vehicle is illustrated in Figure 2-2. The LSI A/A37G-9 autopilot and control mode logic are based on Reference 6, the basic aerodynamics on Reference 7, and the hot day engine $(105^{\circ} F)$ at 5,000 feet on Reference 8. The initial launch velocity, pitch attitude, and pitch attitude command were varied while altitude rate, elevon position, angle of attack, separation distances, and other performance and dynamic parameters were monitored. The simulated vehicle was flown in real-time and slower than real-time to properly look at the initial launch in detail. Reference 9 documents the atmospheric model used in the analysis. Equations were derived for the 1962 Standard Atmosphere and modified for the hot day analysis.

A commonly used procedure for off-standard days is to keep the static pressure constant at a specific altitude and vary the temperature which affects the speed of sound, Mach number, and dynamic pressure. Thus, the pressure altitude of 5,000 feet was used with a temperature of 105°F. As altitude was increased above the launch point, the temperature decreased at its standard atmosphere temperature gradient.

Assumptions

The following assumptions were made in the analysis:

- a. BQM-34F with IR pods and external fuel tank and full fuel with LSI A/A37G-9 autopilot was the configuration considered.
- b. Since the catapult design is not known, ground effects and any initial interference effects with the catapult hardware could not be considered.
- c. The worst case configuration and conditions analyzed were as follows:
 - (1) Heavy weight, 3,000-pound aircraft
 - (2) Forward center-of-gravity limit, X_F 259.04 inches (15% \overline{c})
 - (3) Launch altitude of 5,000 feet (pressure altitude)
 - (4) Atmospheric temperature of 105°F
 - (5) Moments of inertia increased by mass ratio from nominal to heavy weight

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- (6) Total wind vector: 35 knots head or 15 knots side or tail wind
- (7) Lateral engine asymmetry of 1 percent gross thrust applied at tailpipe
- (8) Aerodynamic asymmetries as follows:

 $\Delta C_v = 0.0017$ (side force coefficient)

 $\Delta C_{L} = -0.000679$ (rolling moment coefficient)

 $\Delta C_n = -0.001032$ (yawing moment coefficient)

- d. A good launch was assumed using the following criteria:
 - (1) Positive altitude rate after launch
 - (2) Increasing velocity during climbout
 - (3) An elevon control surface should not be on the stops for more than 3 seconds during a transient
 - (4) Bank angle less than 40 degrees
 - (5) Angle of attack less than 20 degrees
 - (6) Launch Mach number less than 0.9

Results

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The following results were determined:

- a. After analyzing the worst case condition without asymmetries, a RELEASE mode total pitch command of 25 degrees requires the lowest launch velocity as shown in Figure 2-33. This is the same value used for ground launch; so no autopilot hardware changes are required using this value.
- b. The good launch boundary considering asymmetries and 25 degrees pitch command is shown in Figure 2-34. Angle of attack and Mach number limitations are evident. The other boundary represents control surface and altitude rate limitations. The control limit boundary is somewhat odd



Figure 2-33. Effect of Pitch Command on Minimum Launch Velocity (BQM-34F Catapult Launch)

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ASSUMED WORSE CASE CONDITION

ALTI' DE:5000 FEETTEMPERATURE:105 DEGREE FWEIGHT:3000 POUNDSC.G. STATION:259.04 INCHES (15% c)WIND:0 TO 35 KNOTS HEAD OR 15 KNOTS SIDE OR TAILPITCH COMMAND:25 DEGREESINITIAL PITCH RATE:0 DEG / SEC.ENGINE R. P. M. : 100%ENGINE ASYMMETRIES:1% LATERALAERODYNAMIC ASYMMETRIES



Figure 2-34. Good Launch Boundary (BQM-34F Catapult Launch)

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because it is a dynamic limit. Further, the fuel tanks are not completely full, and center-of-gravity variations with fuel angle (considering fuel loading) were used in the analysis.

- c. An initial pitch attitude of 10 degrees plus or minus 1 degree is recommended after analyzing the climb-out from catapult separation for the boundary conditions.
- d. A minimum end velocity of 450 feet per second is required to satisfy the envelope of possible launch conditions (Figure 2-34, attitude of 10 degrees).
- e. The lowest launch velocity can be attained with an engine setting of 100 percent rpm. Thus, it is a requirement.
- f. After investigating the range of winds, the tail wind of 15 knots combined with the aerodynamic and engine asymmetries gives the worst case.
- g. Some of the dynamic parameters are presented in Figures 2-35, 2-36, and 2-37. The results using the selected pitch attitude (10 degrees) and velocity (450 feet per second) to satisfy the worst case launch condition are shown in Figure 2-35. Decreasing the launch attitude to 8 degrees for the same velocity will result in an initial loss of altitude as illustrated in Figure 2-36 on the fine climb rate scale. Below 10 degrees, the required launch velocity becomes very large to prevent the vehicle from initially dropping. For pitch attitudes above 10 degrees, the control surface tends to go to the up stop of 12 degrees for an extended period of time. Figure 2-37 presents the results for 12 degrees. With the controls on the limit, additional asymmetries could cause the vehicle to roll uncontrolled. The good launch boundary showed the lowest velocity required to be at 16 degrees. However, due to the uncertainties in the aerodynamics at high angles of attack and the above reasons, going above 10 degrees would be questionable at best. Figure 2-38 shows the trajectory for the selected worst case condition.
- h. The results showed the vehicle will lose altitude first before it rolls 40 degrees.



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Launch Velocity = 450 Ft./Sec.

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Velocity = 450 Ft. /Sec.

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LAUNCH VELOCITY: 450 FT. /SEC. (100% RPM) LAUNCH ATTITUDE: 10 DEG. ALTITUDE: 5000FEET TEMPERATURE: 105 DEG. F

PITCH COMMAND; 25,DEG TAIL WIND; 15 KNOT3 ENGINE ASYMMETRIES; 1 % LATERAL AERODYNAMIC ASYMMETRIES FORWARD C, G, LIMIT; 259, 04 INCHES

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Figure 2-38. Worst Case Trajectory (BQM-34F Catapult Launch)

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i. The effect of lateral asymmetries on a good launch is to increase the minimum launch velocity from 420 to 450 feet per second.

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- j. Zero lift pitching moment variations show that while the simulation model agrees well with flight data, the values used in the analysis are somewhat conservative.
- k. Initial pitch rate has some effect on launch. For 10 degrees per second, the velocity can be lowered from 450 to 440 feet per second and for 20 degrees per second from 450 to 430 feet per second.
- 1. While the worst case was only assumed, the following conditions were checked:
 - (1) The forward center of gravity limit is in fact worst than aft center-of-gravity limit.
 - (2) 105°F at 5,000 feet is in fact worse than 59°F at sea level.
 - (3) Heavy aircraft launch is worse than light aircraft launch.
- m. Other flight conditions will produce a flight profile where the aircraft climbs faster than the worst case shown in Figure 2-38.
- n. The weight variation results for the worst case configuration and lighter weight configurations are illustrated in Figures 2-39 and 2-40 for the following configurations assuring forward center-of-gravity limits in all cases:
 - (1) 3,000 pounds, full fuel
 - (2) 2,500 pounds, full fuel
 - (3) 2,100 pounds, 11 pounds exsernal fuel
 - (4) 1,700 pounds, no external fuel tank


Figure 2-39. General Trend of Vehicle Weight on Velocity Requirements (BQM -3. F Catapult Launch)

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The general trend of the required launch velocity versus vehicle weight is shown in Figure 2-39. The actual values will depend on the airframe configuration such as IR pods on or off, fuel tank on or off, center-of-gravity range, and vehicle inertias. Figure 2-40 presents the effect of reducing weight and initial velocity on the launch trajectory. The performance is better with a lower weight, even though the initial velocity is lower. The other initial launch dynamics for the lighter weight vehicle are similar to that presented for the heavy weight configuration. The 1,700-pound weight is not a very realistic condition since there is not much fuel in the vehicle.

o. Preliminary analysis showed that launching in RELEASE mode appeared to be better than launching in other modes such as CLIMB or SUBSONIC MACH HOLD mode. The autopilot command procedure (mode switching) should be considered in another study after the launch vehicles and catapult launcher configurations are determined.

Conclusions

For the assumed worst case analyzed:

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- a. The vehicle should be launched at 10 degrees pitch attitude with at least 450 feet per second catapult launch velocity and the engine running at 100 percent rpm.
- b. No autopilot changes are required. The present ground launch pitch attitude command of 25 degrees can be used.
- c. Further reductions in velocity can be made by decreasing vehicle weight or by an initial pitch rate.

3.0 REFERENCES

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APPENDIX

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POTENTIAL HAZARD ANALYSIS

TRA REPORT TELEDYNE 16655-27 PREP B RYAN AERONAUTICAL OF SHEET 1 26 APP BY - ,-REL 5/1/74 REV BQM-34A/F **N** / APP BY W. T. IMMENSCHUH REV REV **SUBJECT** POTENTIAL HAZARD ANALYSIS OF PROPOSED CATAPULT/SPA INTERFACE PREPARED AS PART OF DATA ITEM A002 UNDER CONTRACT F04606-73-A-0048/SC18 #xhambaif 5-1---1 APPROVED BY: DATE: F. X. Marshall Director, Target Programs & Services DATE: <u>5-9-74</u> APPROVED BY: A. Petrofsky Program Manager - Subsonic Targets L. 12777 DATE: 5-7-74 4. APPROVED BY: < + B. F. Owens Program Manager - Supersonic Targets R-55D-13 Preceding page blank A-3

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|---------|-------------|---------------------------|-------|-------|--------|
| BQM-34A | /F AND CATA | APULT INTERFACE | REL 5 | 2 OF | 26 |
| | | TABLE OF CONTENTS | | | |
| SECTION | | | | PAGE | |
| 1.0 | INTROL | DUCTION | | 3 | |
| | 1.1 | Purpose | | 3 | |
| | 1.2 | Scope | | 3 | |
| | 1.3 | Procedure | | 4 | |
| | 1.4 | Basic Assumptions | | 6 | |
| 2.0 | FINDIN | GS | | 7 | |
| | 2.1 | Hazard Categories | | 7 | |
| | 2.2 | Numerical Index | | 8 | |
| | 2.3 | Potential Hazard Matrix | | 8 | |
| 3.0 | CONCLU | SIONS AND RECOMMENDATIONS | | 26 | |
| | | | | | |
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| | TRA REPORT 16655-27 |
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| POTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET 3 OF 26 |
| | REL 5/1/74 REV |

1.0 INTRODUCTION

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1.1 <u>Purpose</u> - The purpose of this report is to document the results of a study that was conducted by Systems Safety Engineering Group. The purpose of this study was to identify any potential Category III or IV hazards to equipments and/or personnel associated with a yet to be designed catapult - launcher for BQM-34A/BQM-34F Teledyne Ryan SPA.

1.2 <u>Scope</u> - The scope of this study was limited to potential hazards that could be associated with a SPA/catapult interface. This catapult is to be designed, manufactured and tested by a still to be determined contractor. Safety design criteria given in this report should be considered wherever appropriate in order to eliminate, reduce or control hazards that could be associated with this SPA/catapult interface.

> In as much as no specific information is available on the catapult and its equipments at this time, this analysis is necessarily of a general nature and addresses itself to past experiences in other methods of launching a SPA. It has been found that the same general types of hazards exist regardless of the type of energy, equipments and procedures that are utilized to bring a SPA to acceptable launch conditions.

> > TELEDYNE RYAN AERONAUTICAL

| | TRA REPORT 16655-27 |
|--|---------------------|
| POTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET 4 OF 26 |
| | REL 5/1/74 REV |

1.2 (continued)

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The potential hazard analysis was conducted without the benefit of any other Preliminary Hazard Analysis (PHA), System Hazard Analysis (SHA) or Subsystem Hazard Analysis (SSHA), of either the basic BQM-34A/BQM-34F SPA or their ground launcher. Lack of this type of previous analysis further detracts from any specific details in this report.

This report is prepared for submittal and approval as a supplement to another Technical Report, Data Item A002 of Contracts Data Requirements List (DD1423) dated 7 February 1974 Contract No. F04606-73-A-0048.

- 1.3 <u>Procedure</u> The following basic steps and preliminary analyses were taken in developing this report:
 - a. A review was made of problems known through experience on similar SPA and other techniques of launching to determine whether they could also be present in this type of SPA/Catapult interface.
 - b. Assumptions were made of the possible use, environments and basic performance characteristics of a catapult to determine the overall spectrum of possible hazards that might be present.

TELEDYNE RYAN AERONAUTICAL

R-550-14

| | TRA | REPOR' | Т | 16655-27 |
|--|-------|--------|-----|----------|
| POTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET | 5 | OF | 26 |
| | REL 5 | 1/74 | REV | / |

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- c. A catapult system of launching TRA's SPA was never utilized; therefore, an in-house survey of personnel who had previous experience with manned aircraft catapult systems (steam, hydraulic and explosive charge) was made to explore any similarity of hazards that might also be inherent in the proposed SPA catapult system.
- d. Information on operational and accident experience pertaining to other catapult systems was requested on 28 March 1974 by ASD/RWDO from the following sources in order to obtain statistical accident and failure information rate:

U. S. Naval Safety Center NAS Norfolk, Va.

Air Force Flight Dynamics Laboratory?FEM Wright-Patterson Air Force Base Ohio 45433

Naval Air Engineering Laboratory NAEC Naval Base Philadelphia, Pa. 19112

All-American Engineering Company Development Division 801 South Madison Street, Box 124/ Wilmington, Delaware 19899

As of this writing, no information has been received to assist in this analysis. In the event data is received that would add to or change anything presented in this report, it will be submitted as an attachment to this analysis.

TELEDYNE RYAN AERONAUTICAL

R-55D-14

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| POTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET | 6 | OF | 26 |
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1.4 Basic Assumptions

- 1.4.1 The qualitative nature of this analysis indicates that the identification of potential hazards associated with this interface be premised upon experience on other somewhat similar systems or su.systems rather than upon all conceivable conditions, situations and failures.
- 1.4.2 No specifics are available as to the actual type of catapult and its associated equipments, AGE and procedures; therefore, the approach to this study is of a broad brush, general nature survey in order to ratalog not only the obvious potential hazarls but some insidious ones that might escape the designer not familiar with past problems in this area.
- 1.4.3 It was also assumed during this analysis that no modifications will be made to the SPA; therefore, the various hazards associated with the SPA/launcher interface must be taken into consideration during the design of the catapult itself.
- 1.4.4 Only Category III and IV hazards were considered during this antlysis. Paragraph 2.1 defines these categories as taken from MIL-STD-582 and made applicable to unmanned aircraft.

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| | REL 5/1/74 REV |

2.0 FINDINGS

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- 2.1 Hazard Categories as more explicitly defined below generally conform to these listed in MIL-STD-882. These categories have been applied to the potential hazards as listed in Table I.
 - Category I Minor damage to SPA or launcher/equipments, consequences to normal operation damage less than 2% of cost of SPA/catapult.
 - Category II Moderate damage to SPA/ atapula, major component, or minor injuries (non-hospitalization) to personnel.
 - Category III Major damage to SPA launcher and associated equipments/facilities, serious injury to personnel, and others not part of the operation.
 - Category IV Catastrophic loss of SPA, launcher or associated equipments, ground facilities and/or permanent crippling injuries or death of personnel.

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| | TRA REPORT 16655-27 |
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| POTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET 9 OF 26 |
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2.3.4 The third column identifies the hazard effect (the consequence(s) of the undesirable event). In addition, a numeral index of the relative probability of occurrence is in parentheses for the hazard effect as defined in paragraph 2.2.

2.3.5 The fourth column indicates mazard category as defined in paragraph 2.1.

2.3.6 The last column titled REMARKS presents a preventative or corrective measure that should be taken into consideration in order to prevent or minimize the hazard. These predetermined actions and/ or procedures are premised upon experience with other somewhat related systems and might prevent either the occurrence of the hazardous condition or its consequences.

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| POTENTIAL | HAZARD | ANALYSIS | - | CATAPULT/SPA | INTERFACE | |
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| SHEET | 8 | OF | 26 |
| REL | 5/1/74 | REV | / |

2.2 Numerical Index of the Relative Probability of occurrence shown below is an attempt to qualitatively estimate how often a particular hazard effect will occur given that the hazard is present. Th. ' numerical index is shown in the third columns of Table 1.

| Numerical Index | Qualitative Estimate of Occurrence | Order of Magnitude Estimate of Occurrence |
|--------------------|---------------------------------------|--|
| 1 | Extremely Low | One in a Million |
| 2 | Very Low | One in a Hundred Thousand |
| 3 | Low | One in Ten Thousand |
| 4 | Moderately Low | One in a Thousand |
| 5 | Moderately High | One in a Hundred |
| 6 | High | One in Ten |
| 7 | Very High | Fifty-Fifty |

2.3 Potential Hazard Matrix

2.3.1 Table 1 is a tabulation of the potential hazards found in the conduct of this analysis.

2.3.2 The sequence number given in the first column is provided for identification purposes only and does not denote any priority or sequential nature of the potential hazard defined.

2.3.3 The second column describes the potential hazard (situation, condition or action which leads to an undesirable event).

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| <u>a</u> . | OTENTIAL | HAZARD | ANALYSIS SPA/LARYONER LYTERE | <i></i> 7 | SHEET 10 OF 26 Rel 5/1/74 Rev |
| No. | Potential | Hazard | Hazard Effect | lCat | . Remarks |
| | ott of Tolfrad 61 Tolen Spalea | C :: ALICNNENT FAPULT. | PERSTRUE LOSS OF SPA MAUKO LAUNC PRASTRUE TO MIS-AUTGREPRE. | 1 | DESTON SLOULD DETVERT ANY INADVERTENT GROSS MIS- ALFCEMELTS. USL OF ACCURATE AND CALJBRATED ALIGENENT AGE. |
| N | COULICATED AN SUL-DP AND ALL SUL-TRAINED P WED TRAINED P | D OVERLY INVOLVA GERLAT PROCEDURE RELNCED AND VERY IRSOMEL. | POSTULE LOSS OF SEA DUE TO TRADE OPALE TUR, TRADILE ADPOR LACK PUPERIENCED AND SAPEDVISORY PERSO PUPERIENCED AND SAPEDVISORY PERSO PUPERIENCED AND SAPEDVISORY PERSO | - IV 805 8151. | (A) ALIGREAT PROCEDURES SHOPED FE STRPLIFIED AND AREA TO BE ACCORPLISHED BY RELATIVILY LEEVERILSHED BY G. ALIGRMENT PROCEDURES SHOULD AND TIME CONSUMING. |
| м Эмерикананан (1996) | AALFDACTION OR HANDLING LUU DOU DADING OR DOU MI APLEL DOLLY | AO VALUAR OF AN | (A) MARO STRUCTURAL DAMARE TO SP. AND/OR CATAPULT EQAIPEDATTS. (A) SLRFOUS PERSONTEL INJARY. (5) | | GFI: (OUTSTER: THE SCOPE OF TITE AMARYETS). |
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|) | ULENIAL HAZAF | A A | NALYSIS SPA/LALNCHUR INTERPACE | | SHEET 11 OF 26 |
| | | | | | REL 5/1/74 REV |
| No | Potential Hazard | | Hazard Effect | Cat. | Remarks |
| 4 | CARLESS OR INPROPER OPI OF HAMDLING EQUIPHAT DU EP-LOAD OR DOWY-LOAD OF CATAPUTT DOLLY. | RATION RING SPA ON | (A) TALO DAMAGE TO SPA AID/OR FARAPULT EQUIPMENTS. (B) SERIOUS PERSONAUL INJURY. (5) | | (A) PROCEDURAI UNSTRUCTIONS SHOUTD BE SPECIFIC WITH APPROPRIATE CAUTIONS/ WARAINGS. (B) USE TRAIN D PERSONNEL WITH PROPER SUPERVISION AND SAFETY MONITORS DURING PAR- TICULARLY HAZARDOUS STEPS |
| ∽ ↓ | FATLURE OF VEHTCLE HOLD DURING ENGINE RUN CAUSIN "RUVAWAY DOLLY". | BACK G A | SERIOUS DAMAGE OF SPA IF NOT PROPERLY ARRESTED. (6) | 111 | IN THE UP (OR DOWN LOAD) CYCLE. (A) CONDUCT TESTS TO DEMON- STRATE HOLLBACK CAPABILITY. (B) CONDUCT TESTS TO DEMON- STRATE ARRESTING CAPABILITY OF SPA/DOLLY VEHICLE. |
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| ā. | DTENTIAL | HAZARD | ANALYSIS | SPA/LAUNCHER INTURF | ACE | SHEET 12 OF 26 |
| | | | | | | REL 5/1/74 REV |
| No. | Potential | Hazard | Hazard E | ffect | lCat. | Remarks |
| ۍ ۲ | IMPROPER CAB L CONVECTIOPS. | ING AND UMBILIC | AL POSSIBLE LOSS 0 PLASE. | J S''A DURF'G LAUNCH | IV | (A) ALL CABLING BETWEEN SFA AND LAUNCHER SHOULD 3E DESIGNED TO RE ROUTED IN ONE WAY ONLY WITH NO CHANCE OF WAY ONLY WITH NO CHANCE OF MIS-MATCH, SHORT, DISCONNECT, INTERFERENCE OR FAILURE AT A CRITICAL PHASE JUST PRIOR TO OR DURING THE LAUNCH. |
| | INSTFFICTENT C SPFED RESULTIN (END SPEED BELL | ATAPULT RELEASF I. IN STALL OF SI M V _{STALL} OF SP | PA A). (7 | ~ | Л | CATAPULT DESIGN TO INCLUDE CAPABILITY TO ACCURATELY MONITOR AND CONTROL END SPELD OF SPA FOR ALL CON- DITIONS OF WEIGHT, TEMP./ ALT. AND WIND CONDITIONS. IF AN ABORT CAPABILITY IS NOT PART OF INITIAL DESIGN, CONSIDERATION SHOULD BE GIVE.3 FOR SOMI TYPE OF COM- TRULLED ARRESTMENT OF SPA/ DO LY WITH MINIMUM DAMAGE AND TO HAZARD TO PENSONNEL. |
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| | | | | | | REL 5/1/74 REV |
| NO. | Potential Ha | Izard | Hazard E | ffect | ·Cat. | Remarks |
| 30 | LNCORRECT SETTINGS CATAPULT CONTROL P PENSATE FOR DIFFER TEMPFRATURE, WIND | PUT INTO ANEL TO COM- HENCES OF CONDITIONS, | POSSILLE LOSS 0 | F STA DURING LAUNCH | 11 | (A) SETTINGS PUT INTO ANY TYPE OF "CATAPULT CONTROL PAMEL" SHOULD BE DISPLAYED FOR THE LAUNCH CONTROL |
| | SPA WEIGHT, ENCINE | THRUST, ETC. | • | | | OFFICER. (B) THESE SETTINGS SHOULD BE DISPLAYED AS MATCHED-UP WITH ACTUAL, REAL-TIME COUDITIONS. |
| 0 | PREMATURE RELEASE HOLP BACK BEFORE T LEVEL OF CATAPULT A PRE-DETERTINED | OF VEHICLE HE TENSION HAS KÄACHED EVEL. | POSSIBLE LOSS J | F SPA DUE TO INSUFF | 2 1 | (A) THE HOLD BACK FITTING SHOULD BE DESIGNED TO RE- LEASE (RUPTURE IN TENSION) AT SOME PRE-DETERMINED TEN- SION LOAD. SION LOAD. (B) THIS HOLD-BACK FITTING (A) THIS HOLD-BACK FITTING (A) THIS HOLD-BACK FITTING (B) THIS HOLD-BACK FITTING |
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| ă | DTENTIAL HAZARD AI | NALYSIS SPA/LAUNCHLR INTERFACE | | SHEET 14 OF 26 |
| | | | | REL 5/1/74 REV |
| No. | Potential Hazard | Hazard Effect | Cat. | Remarks |
| J T | STRUCTURAL FAILURE OF SPA/ CATAPULT DOLLY INTERFACE DURING ENGINE RUN OK LAUNCH. | POSSIBLE LOSS AND MAJOR DAMAGE TO CATAPULT LAUNCHER. (5) | IV | LOADS IMPOSED DURING THE LALNCH NOT TO EXCEED THE EXISTING RATO ATTACHMENTS LIMITS. (SEE FINAL REPORT FOR ANALYSIS OF LIMIT LOADS.) |
| | ACCIDENTAL EJECTION OR RETRACTION OF UMBILICALS. | INJURY TO MAINTENANCE PERSONNEL OR DAMAGE TO EQUIPMENTS. (4) | II II | (A) PROVIDE POSITIVE SAFETY LOCKING DEVICES THAT SHOULD BE INSTALLL) DURING MAINTEN- AMCE OPERATIONS. AMCE OPERATIONS. (B) THESE SAFETY LOCKING (B) THESE SAFETY LOCKING (B) THESE SAFETY LOCKING (B) THESE SAFETY LOCKING THESE SAFETY LOCKING STREAMER SATTACHED TO IN- SURE REMOVAL. |
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| <u>a</u> | DTENTIAL HAZARD | ANALYSIS SPA/LAUNCHER ITTERF | PACE | TRA REPORT 16655-27 SMEET 15 OF 26 |
| | | | | REL 5/1/74 REV |
| No. | Potential Hazard | Hazard Effect | Cat. | Remarks |
| 12 | CATAPULT ATTACHMENT FAILS TO RELEASE FROM SPA AT REQUIRED RELEASE POINT. | C/TASTROPHIC LOSS OF SFA WITH MAJOR DATAGE TC CATAPULT EQUIPMENTS. (5) | IV | (A) DESIGN SHOULD BE FAIL SAFE. RELEASE SHOULD <u>NOT</u> BE DEPENDENT ON ANYTHING BUT ADE(A, AFE FLYING SPEED. (B) PERFORM TESTS FO DEMON- STRATE THAT SPA WILL BE PROPERLY RELEASED. |
| 19 | MALFUNCTION OF UMBILICA' EJECTION/RETRACTION MECHANISH DURING LAUNCH THASE. | DALLAGE TO IMBILICAL MECHANISM OR SPA. (6) | III | THE S.O.W. PROHIBITS ANY MODIFICATION ON VEHICLE. THE CATAPULT MANUFACTURER MUST PROVIDE PROVISIONS TO ACCOMMODATE EXISTING METHOD OF UMBILICAL RELEASE. |
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|-----|---|---|-------|---|
| No. | Potential Hazard | Hazard Effect | JCat. | Remarks |
| 1 | SPA STRIKES CATAPULT AS IT 1S RELEASED AT END OF POWER STROK | POSSIBLE LOSS OF SPA IF THE DRAG OR MAIN CHUTE CANS STRIKE SOME PART OF CATAPULT EQUIPMENTS. | ΛI | (A) INSURE THAT THERE IS A POSITIVE SEPARATION OF SPA AND CATAPULT DOLLY AT IN- STANT OF RELEASE. (B) PERFORM TESTS WITH DUMENY LOAD ON CATAPULT TO DEMON- STRATE SAFE AND POSITIVE SEPARLION. |
| 15 | CATAPULT INTERFACE WITH SPA INDICES A PITCHING, ROLLING OR YAWING MONENT TO SPA AT RELEAS | SPA'S FLIGHT CONTROL SYSTEM MIGHT NOT BE ABLE TO CONPENSATE FOR THE VARIOUS COMBINATIONS OF MOMENTS AT THE LOW END-SPEED. LOSS OF SPA IF BEYOND LIMITS OF FLIGH CONTROL SYSTEM. (6) | 2 | (A) CATAPULT DESIGN TO IN- SURE THAT THESE MOMENTS IMPARTED TO SPA (IN ALL CON- FIGURATIONS) ARE IN THE SPA'S CONTROL EFFECTIVENESS RANGE WITHIN THE LAUNCH ENVELOPP. |
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| PC D | TENTIAL HAZARD AN | NALYSIS SPA/LAUNCHER INTERFACE | | TRA REPORT 16655-27 SHEET 17 OF 26 |
|---------------|--|--------------------------------|------|--|
| No. | Potential Hazard | Hazard Effect | Cat. | Remarks |
| 9 | ACCIDENTAL RELEASE OF ANY HIGH ENERGY SOURCES THAT ARE BEING STORED TO PROPEL THE CATAPULT (GAS, STEAM, HYDRAULIC OR MECHANICAL STORED ENERGY SUCH AS INERTIA WHEEL). | (6) | ^I | (A) PROCEDURES MUST BE DEVELOPED TO INSURE THE ENERGY SOURCE USED TO LAUNCH THE SPA, IS ADEQUATELY CONTROLLED, PRO- TECTED AND SAFE-GUARDS INCOR- PORATED TO PREVENT ACCIDEN- TAL RELEASE. (B) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE <u>NOT</u> (B) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE LAR (B) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE LAR (A) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE LAR (B) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE LAR (B) DESIGN SHOULD BE SUCH THAT ENERGY SOURCE LAR (B) DESIGN SHOULD BE SUCH (B) DESIGN SHOULD BE SUCH (B) DESIGN SHOULD BE SUCH |
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| TRA REPORT 16655-27 SHEET 18 0F 26 REL 5/1/74 REV | Remarks | (A) ADHERE TO ENVIRONMENTAL SPECIFICATION REQUIREMENTS. (B) ANALYSIS AND FUNCTIONAL TESTING SHOULD BE CONDUCTED UNDER VARIOUS PREDICTEL UNDER VARIOUS PREDICTEL OPERATIONAL ENVIRONMENTAL CONDITIONS. (C) PROTECTION OF CRITICAL PARTS AND COMPONENTS FROM MOISTURE, DUST, ETC. | 3 |
|---|------------------|--|----------------|
| ACE | Cat. | IV | |
| ALYSIS SPA/LAUNCHER INTERU | Hazard Effect | POTENTIAL MALFUNCTION OF CATAPULT AND NESULTANT DAMAGE OR DESTRUCTION OF SPA (5) | |
| TENTIAL HAZARD ANA | Potential Hazard | ADVERSE ENVIRONMENTAL CONDITIONS P SUCH AS HEAVY RAIH, DUST OR FREEZING CONDITIONS ON AN EXPOSED SPA/ LAUNCHER. | |
| bO | No | | 4 b |

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| ă. | JTENTIAL HAZARD AN | VALYSIS SPA/LAUNCHER INTERFACE | | SHEET 19 OF 26 |
| | | | | REL 5/1/74 REV |
| No. | Potentis: Hazard | Hazard Effect | Cat. | Remarks |
| 18 | INADEQUATE IDENTIFICATION AND | SERIOUS PERSONNEL INJURY. | 111 | (A) INSTALL APPROPRIATE |
| | CONTROL OF POTENTIAL HAZARDOUS | | | WARNING & CAUTION SIGNS. |
| | EQUIPMENTS, CONDITIONS, | | | (b) PROVIDE PROTECTIVE PER- |
| | OPERATIONS OR AREAS PERTAINING | | | SONNEL BARRIERS TO KEEP UN- |
| | TO THE SPA/LAUNCHER COMPLEX. | (4) | | AUTHORIZED PERSONNEL OUT OF |
| | | | | A SPECIFIC AKLA. |
| | | | | (C) PROVIDE SAFETY INTER- |
| | | | | LOCKS OR CUT-OUT CIRCUITRY |
| | | | | TO CONTROL EQUIPMENTS THAT |
| | | | | COULD BE HAZARDOUS TO PER- |
| | | | | SONNE 1. |
| | | | | (D) TECH DATA ON CATAPULT |
| | | | | LAUNCHER SHOULD PROVIDE A |
| | | | | SUMMARY SECTION OF ALL |
| | | | | HAZARDOUS EQUIPMENTS THAT |
| | | | | PERSONNEL SHOULD BE |
| | | | | SPECIFICALLY AWARE OF. |
| | | | | |
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| | | | | REL 5/1/74 REV |
| No. | Potential Hazard | Hazard Effect | Cat. | Remarks |
| 19 | CATAPULT DESIGN RESULTS IN SPA MAINTENANCE, SERVICING, AND INSTALLATION DIFFICULTIES. | POTENTIAL OF INJURY OR DAMAGE TO SPA AND/OR LAUNCHER AS PEKSONNEL TAKE SHORT CUTS OR ESTABLISH JURY RIGS TO WORK AROUND THESE DIFFICULTIES. (4) | 111 | DESIGN SHOULD ALLOW EASY ACCESS TO ALL COMPONENTS OF SPA/CATAPULT.THAT WILL RE- QUIRE MAINTENANCE, SERVICING OR ADJUSTMENT. |
| 20 | JET ENGINE EXHAUST INFINCEMENT ON CRITICAL PARTS OF CATAPULT ASSEMBLY. | MAJOR DAMAGE TO CATAPULT COULD CAUSE A MALFUNCTION DURING LAUNCH, POTENTIAL OF LOSS OF SPA. (4) | III AND/OR IV | DESIGN·SHOULD PROVIDE FOR ADEQUATE SHIFLDING AND BLAST DEFLECTORS TO INSURE THAT CRITICAL PARTS OF LAUNCHER ARE NOT AFFECTED BY THE HEAT OR JET EXHAUST. |
| 5 | FIRE IN SPA OR AROUND CATAPULT DUE TO FUEL VENTING, SPILLAGE OR IMPROPER ENGINE START OR SECURE. | LOSS OF SPA AND MAJOR DAMAGE TO CATA- PULT IF FIRE CANNOT IMMEDIATELY BE CONTROLLED WITHOUT ENDANGERING PERSONNEL. | | INSTALL FIRE SUPPRESSION SYSTEM AND MEANS CAPABLE OF CLEARING SPILLED FUEL & EXTINGUISHING ANY FIRE. |
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| þ | DTENTIAL | HAZARD A | NALYSIS SPA/LAUNCHER INTER | RFACE | TRA REPORT 1665527 SMEET 21 OF 26 |
|-------------------|---|---|--|-------|--|
| No. | Potential | Hazard | Hazard Effect | Cat. | Remarks · |
| 22 | BLAST DEFLECTOR DROPFED WHILE PI WORKING IN THIS | IS INADVERTENTL' ERSONNEL ARE AREA. | K SERIOUS INJURY TO OR DEATH OF PER- SONNEL IF STRUCK BY BLAST DEFLECTOR. (5) | IV | PROVIDE POSITIVE LOCKING OF ANY TYPE OF MOVABLE BLAST DEFLECTOR WHILE IN "UP" POSITION BY INSTALLATION OR REMOVABLE PIN. THIS PIN TO HAVE "REMOVE PRIOR TO LAUNCH" STREAMER ATTACHED. INCORPORATE APPROPRIATE WARNINGS IN TECH. DATA. |
| 23 | POSSIBILITY OF I WITH BLAST DEFLE POSITION. FAILUF CATAPULT FIRE SV ALREADY FAILED (TIME A, LAUNCH CC | AUNCHING SPA SCTOP IN WRONG KE MODE WOULD BE JITCH THAT IS SLOSED AT THE MMAND IS GIVEN. | SPA WOULD BE CATAPULTED BEFORE DE- FLECTOR RETRACTS OUT OF THE WAY. MAJOR DAMAGE TO SPA/LAUNCHER. (5) | 111 | DESIGN INTERLOCK CIRCUIT TO INSURE BLAST DEFLECTOR IS FIRMLY SECURED IN CORRECT POSITION BEFORE SPA CAN BE CATAPULTED. |
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| ā | OTENTIAL | HAZARD | ANALYSIS SPA/LAU | NCHER INTERF. | ACE | SHEET 22 DF 26 |
| | | | | | | REL 5/1/74 REV |
| No. | Potential | Hazard | Hazard Effect | | Cat. | Remarks |
| | FOD (FOREIGN OI SPA DURING ENG) PULT' STROKE. | BJECT DAMAGE) TO INE RUN OR CATA- | ENGINE MALFUNCTION. POSSIB OF SPA. (4) | LE LOSS | NI | DESTGN SHOULD INSURE THAT FOD DAMAGE TO SPA CANNOT OCCUR DURING ENGINE RUN OR LAUNCH. SCREENS, BAFFLES AND/OR DE- FLECTORS SHOULD BE CONSIDERED IN CATAPULT DESIGN. |
| 2 N | MISLAID TOOLS, AGENTS, OR LOOS MENT ON OR AROU | RAGS, CLEANING SE SUPPORT EQUIP- IND LAUNCHER. | SERIOUS INJURY TO PERSONNEL FUNCTION OF CATAPULT OPLRATI (5) | OR MAL- ION. | | INCLUDE WARNING NOTE IN PRO- CEDURES. PROVIDE INSPECTION ITEM FOR LCO IN PRE-LAUNCH CHECK LIST. PROPER SUPERVISION AND MAIN- TENANCE PRACTICES AROUND SPA AND CATAPULT AREA. |
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| P(| DTENTIAL | HAZARD | ANALYSIS | SPA/LAUNCHER INTER | UFACE | <u>TRA REPORT 16655-27</u> SHEET 23 OF 26 |
|----------|--|---------------------------|--|--------------------------|--------|---|
| | | | | | | REL 5/1/74 REV |
| No. | Potential | Hazard | Hazard Ef | fect | Cat. | Remarks |
| 9 (1) | FAILURE TO PUL PRIOR TO CATAP | JL ALL SAFETY PIN ULT. | IS POSSIBLE LOSS OF DAMAGE TO CATAPL (5) | F SPA WITH MAJOR JLT. | 5 1 | LCO TO PERFORM INVENTORY OF PINS AS PART OF CHECK-LIST PRIOR TO CATAPULTING. ALL PINS TO HAVE RED "REMOVE PRIOR TO FLIGHT" STREAMERS ATTACHED. |
| 2 | INADVERTENT RE DURING THE CAT PHASE. • | APULT LAUNCH | LOSS OF SPA | | NI | DESIGN SHOULD INCORPORATE SOME TYPE OF LOWER LANYARD SWITCH TO PROVIDE FOR LOCK- OUT OF RECOVERY SYSTEM DURING THE CATAPULT LAUNCH. |
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| a | DTENTIAL | HAZARD | ANALYSIS SPA/LAUNCHER INTI | ERFACE | SHEET 24 OF 26 | <u> </u> |
| | | | | | MEL 5/1/74 REV | |
| No. | Potential | Hazard | Hazard Effect | Cat. | Remarks | |
| 73 73 | CUTTER PULSE D RESTRAINING CA SEPARATE SPA F | OES NOT FIRE BLE CUTTER TO ROM DOLLY. | SA WOULD NOT BE RELEASED EVEN THROUG IT HAS ACHIEVED ADEQUATE LAUNCHING VELOCITY. POSSIBLE MAJOR DAMAGE TO CATAPULT AND SPA. (5) | III HS | IF THE FIRE SIGNAL IS ELECTRONICALLY GENERATED AS A FUNCTION OF RELATIVE VELOCITY, THTRE SHOULD BE SOME TYPE OF MECHANICALLY GENERATED "RELEASE PULSE" A: THE DOLLY/SPA PASSES A PRE- DETERMINED POINT ON THE LAUNCHER. (IT IS ASSUMED THAT NO ABORT CAPABILITY EXISTS.) | |
| 2 | AUTOMATIC BRAK MALFUNCTIONS. | ING SYSTEM | DOLLY IS NOT DE-CELERATED AFTER RELEASE OF SPA CAUSING MAJOR DAMAGE TO CATAPULT. (5) | III | DESIGN SHOULD CONSIDER A BACK-UP BRAKE DESIGN OR PRO- VIDE FOR A SAFE OVER-RUN AFTER LEAVING LAUNCHER RAILS | ī vī |
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| 2 | JTENTIAL HAZARD AI | VALYSIS SPA/LAUNCHER INTERF. | ACE | SHEET 25 OF 26 |
| | | | | REL 5/1/74 REV |
| No. | Potential Hazard | Hazard Effect | Cat. | Remarks |
| 30 | THE TURBINE WHEEL PLANE OF SPA'S ENGINE IS CLASSIFIED AS A DANGER AREA DUE TO THE POSSIBILIT OF TURBINE BLADES BEING EJECTED DURING ENGINE RUN. | POTENTIAL OF TURBINE BLADES/SHRAPNEL BEING HURLED AGAINST VULNERABLE Y SECTIONS OF CATAPULT. POSSIBLE SERIOUS INJURY TO PERSONNEL. (4) | III | THE DANGER AREA SHOULD BE Shielded and avoided. |
| те Е | CABLES, ROPES OR TAPES THAT TRANSMIT ENERGY TO DOLLY ARE EXPOSED OR INSUFFICIENTLY COVERED, | SERIOUS INJURY TO PERSONNEL (4) | | ADEQUATE GUARDS AND WARNING SIGNS SHOULD BE UTILIZED. INTERLOCKS SHOULD KEEP THE ENERGY INPUT DEVICES AND CLUTCHES FROM BEING ACTUATED IN THE EVENT THESE GUARDS ARE REMOVED. |

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| OTENTIAL HAZARD ANALYSIS - CATAPULT/SPA INTERFACE | SHEET | 26 | OF | 26 | |
| | REL | 5/1/74 | RE | v | |

3.0 CONCLUSIONS AND RECOMMENDATIONS

- 3.1 This analysis shows that there are a number of hazardous aspects associated with a SPA/launcher interface and all of these potential hazards should be considered in order to formulate design criteria for the proposed catapult launcher. Most of these can be eliminated and controlled by proper design. Others that are beyond reach due to cost and other restraints should be identified in tech data and controlled via appropriate restrictions, procedures and warnings to a degree where the risk level can be tolerated.
- 3.2 It is recommended that a Preliminary Hazard Analysis (FPA) be conducted on the catapult launcher once the basic design has been formulated. This analysis could be used as a departure point and further developed to insure that all hazardous situations have been explored and taken into consideration during the design. Prior to production and operational use of this catapult launcher, an Operational Hazard Analysis (OHA) should be conducted to verify what operating functions could be inherently hazardous to equipment and/or personnel. Results of this analysis would point out any hazardous situations that were not eliminated during design and would provide final inputs for tech data.

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