TECHNICAL MEMORANDUM

PERFORMANCE CHARACTERISTICS OF THE
LITTLE JOE LAUNCH VEHICLE

By Ronald Kolenkiewicz and John C. O'Loughlin

Manned Spacecraft Center
Houston, Texas

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON

September 1962
TECHNICAL MEMORANDUM X-561

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SUMMARY

A summary of performance data is given for the first five Project Mercury Little Joe flights. Some of these data are compared with calculated performance characteristics and are shown to be in good agreement. Curves showing calculated maximum performance characteristics for the Little Joe launch vehicle are presented over a wide range of take-off weights, launch angles, and staging times as an aid in the prediction of performance parameters of the Little Joe launch vehicle when used in future projects.

INTRODUCTION

Little Joe is the designated name of the solid-propellant launch vehicle that was designed by the National Aeronautics and Space Administration to test the Project Mercury spacecraft at certain critical conditions that would be encountered on the exit phase of an earth-orbiting mission. As used in the Project Mercury flight-test program the launch vehicle was conceived as a simple and relatively inexpensive means for determining full-scale Project Mercury spacecraft aerodynamics and proving systems concepts. The launch vehicle is capable of propelling a full-scale Project Mercury spacecraft to speeds up to a Mach number of 6; hence, most of the critical orbital-launch abort conditions can be simulated. Satisfactory performance results have been attained by the first five flights made by the launch vehicle in the Project Mercury program. As a result of its success in this program, it is felt that the launch vehicle or a scaled-up version could be utilized in future areas of research and development. These areas of research and development could include a space trainer for astronauts as well as a check-out for landing, control, navigational, and abort systems.

*Title, Unclassified.
The purpose of this paper is to summarize some of the performance characteristics of the launch vehicle, both calculated and actual, so that an estimate of its performance can be made for future projects.

DESCRIPTION OF LAUNCH VEHICLE

The launch vehicle is fin stabilized and consists of a cluster of solid-fuel rocket motors. The spacecraft is attached to the launch vehicle by means of an adapter. Figures 1 and 2 show the launch vehicle, the adapter, and a simulated Project Mercury spacecraft.

The propulsion system for the launch vehicle nominally consists of a cluster of eight solid-fuel rocket motors — four main motors and four auxiliary motors. The four main motors are either Thiokol Castor (XM-33E2) or Thiokol Pollux (XM-33E4) rocket motors, and the four auxiliary rocket motors are Thiokol Recruit motors (XM-19E1-C12). The general arrangement of the rocket cluster is shown in figure 3, and typical performance characteristics of the solid-fuel rocket motors are shown in figures 4 to 6.

Depending on the mission to be performed, there are four launch-vehicle configurations which are classified by the number and type of rocket motors used. The motors used in the configurations are presented in table I. The four configurations are made possible by the fact that Castor and Pollux motors have the same physical dimensions but the Castor motors have a greater impulse than the Pollux motors. (See figs. 4 and 5.) The ignition sequence for the launch vehicle is the firing of two main motors and four auxiliary motors at take-off and the remaining two main motors (for the type II and type IV vehicles) at a preset time (staging time) after take-off. Both the main and auxiliary rocket motors used in the launch vehicle have canted nozzles. These canted nozzles direct the thrust vector of the motors through the mean center of gravity of the vehicle, and therefore minimize any destabilizing moments that would be caused by motor failure or time differences in ignition and burnout. The cant angle on the main motors is $11^\circ$ measured through the center line at station 496.8, and the cant angle on the auxiliary motors is $12^\circ$ measured through the center line at station 529.4. (See fig. 3.)

The launch vehicle is aerodynamically stabilized by means of four fins. The launch vehicle and the spacecraft shown in figure 1 were designed to have static stability for Mach numbers between 0.0 and 6.0. Wind-tunnel data for this configuration up to Mach number 6.86 are given in reference 1. The thrusting and coasting drag parameter obtained from flight-test and wind-tunnel data is shown in figure 7. These data were corrected for base effects by using flight-test data.
The launch vehicle has large fins to insure static stability at a Mach number of 6.0. As a result, the launch vehicle is extremely stable at the lower Mach numbers. This extreme stability causes difficulty at launch since the vehicle tends to weathercock into the wind and go off course. In order to eliminate some of this weathercocking as well as to decrease the flight-path angle dropoff, the launch vehicle is accelerated rapidly by igniting two main motors and four auxiliary motors at take-off. Even with the high acceleration at take-off, the launch vehicle is sensitive to winds during the first moments of flight. A wind-correction method described in reference 2 has been used successfully on all of the launch-vehicle flights.

RESULTS AND DISCUSSION OF TRAJECTORY DATA

Flight Test

A summary of five flight tests of the Little Joe launch vehicle given in table II includes a list of the figure numbers of the various performance parameters obtained from these tests. The general configuration dimensions for the first four flights were similar to the configuration shown in figure 1. The fifth flight had an additional 18-inch-long adapter between the launch vehicle and the spacecraft in order to accommodate the retrorocket package of the production Project Mercury spacecraft. In the figures presented, the performance parameters for the flight tests were terminated when the spacecraft was separated from the launch vehicle. Note that this was not necessarily launch-vehicle burnout. In general, the data presented in figures 8 to 38 for the first five launch-vehicle flights are: altitude as a function of horizontal range and time histories of altitude, velocity, Mach number, dynamic pressure, and longitudinal acceleration. The exceptions include flight 1, which had no accelerometer and hence no longitudinal acceleration data, and flight 3, in which roll-rate and noise-level data were obtained and presented in figures 25 and 26. The first five flights include all of the launch-vehicle configurations listed in table I. Results of flight 1 are contained in reference 3.

Comparison of Flight Results With Calculated Results

Prior to each launch-vehicle flight a trajectory was calculated. These calculations were carried out on the IBM 704 electronic data processing machine and were essentially the numerical integration of the equations of motion for a point mass in a plane under the influence of gravity, thrust, and drag.
Only the calculations for type I and II launch vehicles are considered in this report since these vehicles exceed the performance of type III and IV launch vehicles, respectively. The only reason for using type III and IV launch vehicles is the fact that Castor rocket motors were not available at the time of some of the flights. Performance of type III and IV launch vehicles can be matched by type I and II launch vehicles by adding some ballast.

The flight-test data are shown in figures 19 to 23 to agree very well with the calculated data for flight 3 (type II launch vehicle). For flight 5 (type I launch vehicle), the flight-test data also agree very well with the calculated data as shown in figures 33 to 37.

Performance Estimates

Results of calculated data which give performance estimates for the type I and type II launch vehicles are given in figures 39 to 63. The maximum values of the trajectory parameters are given as a function of take-off weight, launch angle, and (in the case of type II launch vehicle) staging time. The trajectory parameters considered are: altitude, velocity, Mach number, dynamic pressure, and longitudinal load factor. Table III presents the range of staging times, take-off weights, and launch angles for which these performance estimates were made. The weight and balance for the type I and type II launch vehicles are given in table IV. The performance estimates are based upon the weights given in table IV, the thrusts given in figures 4 and 6, and the drag parameter given in figure 7. The figures showing performance estimates for the Little Joe type I and II launch vehicles are self explanatory and may be used in planning future projects utilizing the launch vehicles.

CONCLUDING REMARKS

The comparisons of calculated and flight-test data for the Little Joe launch vehicle have been shown to agree very well. On the basis of this agreement, more data have been calculated over a wide range of take-off weights, launch angles, and staging times and were presented as curves showing maximum performance characteristics, an aid in the planning of future projects utilizing the launch vehicles.

Manned Spacecraft Center,
National Aeronautics and Space Administration,
REFERENCES


**TABLE I. - LITTLE JOE LAUNCH-VEHICLE CONFIGURATIONS**

<table>
<thead>
<tr>
<th>Launch-vehicle type</th>
<th>Main motors</th>
<th>Auxiliary motors</th>
<th>Little Joe flight</th>
<th>Date launched</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>2 Castor</td>
<td>4 Recruit</td>
<td>5</td>
<td>Nov. 8, 1960</td>
</tr>
<tr>
<td>II</td>
<td>4 Castor</td>
<td>4 Recruit</td>
<td>3</td>
<td>Dec. 4, 1959</td>
</tr>
<tr>
<td>III</td>
<td>2 Pollux</td>
<td>4 Recruit</td>
<td>2</td>
<td>Nov. 4, 1959</td>
</tr>
<tr>
<td>III</td>
<td>2 Pollux</td>
<td>4 Recruit</td>
<td>4</td>
<td>Jan. 21, 1960</td>
</tr>
<tr>
<td>IV</td>
<td>4 Pollux</td>
<td>4 Recruit</td>
<td>1</td>
<td>Oct. 4, 1959</td>
</tr>
</tbody>
</table>
### TABLE II.—SUMMARY OF FIVE FLIGHTS

<table>
<thead>
<tr>
<th>Flight</th>
<th>Launch-vehicle type</th>
<th>Nominal zero wind launcher setting</th>
<th>Actual launcher setting</th>
<th>Wind conditions</th>
<th>Nominal rocket motor ignition sequence</th>
<th>Actual rocket motor ignition sequence</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>True azimuth, deg</td>
<td>Elevation, deg</td>
<td>True azimuth, deg</td>
<td>Elevation, deg</td>
<td>Wind conditions</td>
<td>Rocket motor t, sec</td>
<td>Rocket motor t, sec</td>
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<tr>
<td>1</td>
<td>IV</td>
<td>110</td>
<td>30</td>
<td>94</td>
<td>78</td>
<td>Given in ref. 2</td>
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</tr>
<tr>
<td></td>
<td>2 Pollux</td>
<td>25</td>
<td>2 Pollux</td>
<td>4</td>
<td>110</td>
<td>76</td>
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<td>2</td>
<td>III</td>
<td>135</td>
<td>75</td>
<td>110</td>
<td>76</td>
<td>Given in ref. 2</td>
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</tr>
<tr>
<td>3</td>
<td>II</td>
<td>140</td>
<td>82</td>
<td>157</td>
<td>76</td>
<td>Given in ref. 2</td>
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</tr>
<tr>
<td>4</td>
<td>III</td>
<td>135</td>
<td>77.1</td>
<td>135</td>
<td>70</td>
<td>Given in ref. 2</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>I</td>
<td>135</td>
<td>82.5</td>
<td>145</td>
<td>80.5</td>
<td>Given in ref. 2</td>
<td>0</td>
</tr>
</tbody>
</table>

*Actual ignition sequence erratic because heat from the first two Pollex motors ignited the remaining Pollex motors; this difficulty was corrected in later flights.*
### Table: Center-of-gravity station values

<table>
<thead>
<tr>
<th>Center-of-gravity station</th>
<th>Take-off, in.</th>
<th>Burnout, in.</th>
<th>Altitude range</th>
<th>Altitude time history</th>
<th>Altitude time history</th>
<th>Velocity time history</th>
<th>Mach number time history</th>
<th>Mach number time history</th>
<th>Dynamic-pressure time history</th>
<th>Dynamic-pressure time history</th>
<th>Longitudinal-acceleration time history</th>
<th>Longitudinal-acceleration time history</th>
<th>Full-rate time history</th>
<th>Full-rate time history</th>
<th>Other data presented</th>
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<tbody>
<tr>
<td>390.3</td>
<td>375.6</td>
<td>8</td>
<td>9</td>
<td>10</td>
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<td>12</td>
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<td>No instrumentation</td>
<td>No instrumentation</td>
<td>No instrumentation</td>
<td>No instrumentation</td>
<td>Noise-level data, 26</td>
<td>Other data presented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>388.6</td>
<td>385.28</td>
<td>13</td>
<td>14</td>
<td>15</td>
<td>16</td>
<td>17</td>
<td>18</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>Noise-level data, 26</td>
<td>Other data presented</td>
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<td></td>
</tr>
<tr>
<td>392.0</td>
<td>374.0</td>
<td>19</td>
<td>20</td>
<td>21</td>
<td>22</td>
<td>23</td>
<td>24</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>Noise-level data, 26</td>
<td>Other data presented</td>
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<td>391.5</td>
<td>389.5</td>
<td>27</td>
<td>28</td>
<td>29</td>
<td>30</td>
<td>31</td>
<td>32</td>
<td>32</td>
<td>Poor data</td>
<td>Poor data</td>
<td>Poor data</td>
<td>Noise-level data, 26</td>
<td>Other data presented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>378.5</td>
<td>—</td>
<td>33</td>
<td>34</td>
<td>35</td>
<td>36</td>
<td>37</td>
<td>38</td>
<td>Poor data</td>
<td>Poor data</td>
<td>Noise-level data, 26</td>
<td>Other data presented</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure numbers for -**

- Figure 9: Other data presented
TABLE III. - CALCULATED TRAJECTORIES FOR LITTLE JOE

TYPE I AND TYPE II LAUNCH VEHICLES

<table>
<thead>
<tr>
<th>Launch-vehicle type</th>
<th>Staging time, sec</th>
<th>Take-off weight, lb</th>
<th>Launch angle, deg</th>
<th>Data figures</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Not applicable</td>
<td>24,000 to 49,000</td>
<td>70, 75, 80, 85</td>
<td>39 to 43</td>
</tr>
<tr>
<td>II</td>
<td>19</td>
<td>40,000 to 50,000</td>
<td>70, 75, 80, 85</td>
<td>44 to 48</td>
</tr>
<tr>
<td>II</td>
<td>23</td>
<td>40,000 to 50,000</td>
<td>70, 75, 80, 85</td>
<td>49 to 53</td>
</tr>
<tr>
<td>II</td>
<td>27</td>
<td>40,000 to 45,000</td>
<td>70, 75, 80, 85</td>
<td>54 to 58</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>45,000 to 50,000</td>
<td>80, 85</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>31</td>
<td>40,000 to 45,000</td>
<td>70, 75, 80, 85</td>
<td>59 to 63</td>
</tr>
<tr>
<td>II</td>
<td></td>
<td>45,000 to 50,000</td>
<td>80, 85</td>
<td></td>
</tr>
</tbody>
</table>
TABLE IV.- WEIGHT AND BALANCE FOR LITTLE JOE COMPONENTS

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight, lb</th>
<th>Center-of-gravity station, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>Castor motor, loaded</td>
<td>8,785</td>
<td>403</td>
</tr>
<tr>
<td>Castor motor, empty</td>
<td>1,333</td>
<td>445</td>
</tr>
<tr>
<td>Recruit motor, loaded</td>
<td>364</td>
<td>485</td>
</tr>
<tr>
<td>Recruit motor, empty</td>
<td>100</td>
<td>487</td>
</tr>
<tr>
<td>Booster airframe</td>
<td>2,425</td>
<td>483</td>
</tr>
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</table>

Weight Breakdown for Little Joe Type I Vehicle

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Castor motors, loaded</td>
<td>17,570</td>
</tr>
<tr>
<td>2 Castor motors, empty</td>
<td>2,666</td>
</tr>
<tr>
<td>4 Recruit motors, loaded</td>
<td>1,456</td>
</tr>
<tr>
<td>Booster airframe</td>
<td>2,425</td>
</tr>
<tr>
<td>Total take-off weight(^\text{b})</td>
<td>24,117</td>
</tr>
</tbody>
</table>

Weight Breakdown for Little Joe Type II Vehicle

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight, lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 Castor motors, loaded</td>
<td>35,140</td>
</tr>
<tr>
<td>4 Recruit motors, loaded</td>
<td>1,456</td>
</tr>
<tr>
<td>Booster airframe</td>
<td>2,425</td>
</tr>
<tr>
<td>Total take-off weight(^\text{b})</td>
<td>39,021</td>
</tr>
</tbody>
</table>

\(^\text{a}\) The forward end of the launch-vehicle airframe is at station 302. (See fig. 3.)

\(^\text{b}\) Except for spacecraft and adapter.
Figure 1. - General arrangement of Mercury Little Joe configuration with a simulated Project Mercury spacecraft. When the production Project Mercury spacecraft is used, the adapter has to be lengthened 18 inches in order to accommodate the retrorocket package.
Figure 2.- Little Joe ready for launch.
All linear dimensions are in inches.

SECTION A-A

Figure 3. General arrangement of the rocket cluster for Little Joe launch vehicle.
Figure 4. - Time history of sea-level thrust for one Castor rocket motor with an effective exit area of 2.69 sq ft.
Figure 5.- Time history of sea-level thrust for one Pollux rocket motor with an effective exit area of 2.27 sq ft.
Figure 6.- Time history of sea-level thrust for one Recruit rocket motor with an effective exit area of 0.894 sq ft.
Figure 7.- Drag parameter as a function of Mach number for Little Joe (obtained from a combination of wind-tunnel and flight-test data).
Figure 8.- Altitude as a function of horizontal range for Little Joe Flight 1.

Take-off weight = 41,347 lb
Figure 9. - Altitude time history for Little Joe flight 1.
Figure 10. Earth-fixed velocity time history for Little Joe Flight 1.
Figure 11. - Mach number time history for Little Joe flight 1.

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Take off-weight = 41,347 lb
Figure 12.- Dynamic-pressure time history for Little Joe flight 1.

Take-off weight = 41,347 lb
Figure 13.- Altitude as a function of horizontal range for Little Joe flight 2.
Figure 14.- Altitude time history for Little Joe flight 2.
Figure 15.- Earth-fixed velocity time history for Little Joe flight 2.
Figure 16.- Mach number time history for Little Joe flight 2.

Take-off weight = 26,750
Figure 17.- Dynamic-pressure time history for Little Joe flight 2.
Figure 18.- Longitudinal-acceleration time history for Little Joe flight 2.
Figure 19.- Altitude as a function of horizontal range for Little Joe flight 3.
Figure 20. - Altitude time history for Little Joe flight 3.

Take-off weight = 43,554 lb
Figure 21.- Velocity time history for Little Joe flight 3.
Figure 22.— Mach number time history for Little Joe flight 3.
Figure 23.- Dynamic-pressure time history for Little Joe flight 3.
Figure 24.- Longitudinal-acceleration time history for Little Joe flight 3.
Figure 25.- Roll-velocity time history for Little Joe flight 3.
Figure 26 - Effects of dynamic pressure on the internal noise level within the conical payload for Little Joe flight 3.
Figure 27. - Altitude as a function of horizontal range for Little Joe flight 4.
Figure 28. - Altitude time history for Little Joe flight 4.
Figure 29 - Velocity-time history for Little Joe flight.
Figure 30. Mach number time history for Little Joe flight 4.
Figure 31. Dynamic-pressure time history for Little Joe flight 4.
Figure 32 - Longitudinal acceleration time history for Little Joe flight 4.
Figure 33. - Altitude as a function of horizontal range for Little Joe flight 5.
Figure 34. - Altitude time history for Little Joe flight 5.
Figure 35. - Velocity time history for Little Joe flight 5.
Figure 36. - Mach number time history for Little Joe flight 5.
Figure 37.- Dynamic-pressure time history for Little Joe flight 5.
Figure 38. - Longitudinal acceleration time history of Little Joe flight 5.
Figure 39. - Maximum altitude plotted against spacecraft weight as a function of take-off weight and launch angle for type I launch vehicle.
Figure 40. - Maximum exit velocity plotted against spacecraft weight as a function of take-off weight and launch angle for type I launch vehicle.
Figure 4.1.- Maximum exit Mach number plotted against spacecraft weight as a function of take-off weight and launch angle for type I launch vehicle.
Figure 42.- Maximum exit dynamic pressure plotted against spacecraft weight as a function of take-off weight and launch angle for type I vehicle.
Figure 43. - Maximum exit longitudinal load factor plotted against spacecraft weight as a function of take-off weight and launch angle for type I launch vehicle.
Figure 44. Maximum altitude plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 19 seconds.
Figure 45.- Maximum exit velocity plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 19 seconds.
Figure 45 - Maximum exit Mach number plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 19 seconds.
Figure 47.- Maximum exit dynamic pressure plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 19 seconds.
Figure 48. Maximum exit longitudinal load factor plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 19 seconds.

Take-off weight = 40,000 lb
Launch angle = 70°
Figure 49.- Maximum altitude plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 23 seconds.
Figure 50.- Maximum exit velocity plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 23 seconds.
Figure 51.- Maximum exit Mach number plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 23 seconds.
Figure 52.- Maximum exit dynamic pressure plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 23 seconds.
Figure 53.- Maximum exit longitudinal load factor plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 23 seconds.
Figure 54.- Maximum altitude plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 27 seconds.
Figure 55.- Maximum exit velocity plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 27 seconds.
Figure 56. - Maximum exit Mach number plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 27 seconds.
Figure 57. Maximum exit dynamic pressure plotted against spacecraft weight as a function of take-off weight and launch angle for type III launch vehicle at a staging time of 27 seconds.
Figure 58.- Maximum exit longitudinal load factor plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 27 seconds.
Figure 59.- Maximum altitude plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 31 seconds.
Figure 60.- Maximum exit velocity plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 31 seconds.
Figure 61. - Maximum exit Mach number plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 31 seconds.
Figure 62. Maximum exit dynamic pressure plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 31 seconds.

Maximum exit dynamic pressure, \( \frac{1b}{ft^2} \)

Launch angle = 85°

Take-off weight = 40,000 lb
Figure 63.- Maximum exit longitudinal load factor plotted against spacecraft weight as a function of take-off weight and launch angle for type II launch vehicle at a staging time of 31 seconds.