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STUDY OF A METHOD FOR MODIFYING

TERMINAL TRAJECTORY

PHASE IA, LOTOP PROJECT

RYAN MODEL 109

SC-DC-66-1923X

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1.0 INTRODUCTION

Under contract with the Sandia Corporation, the Ryan Aeronautical Company conducted a Phase I design study of an external store configuration to be used for the "Lotop" low altitude weapon delivery system. This system calls for the store to fly a looping trajectory following release from the parent aircraft. The original design objectives called for the loop to terminate in a vertically downward flight path at least 3000 feet above the launch altitude, at least 20 seconds after launch, and not more than 2500 feet down range from the launch point. The Ryan Model 109G fulfilled these objectives with the following program.

1. Launch downward from parent aircraft by ejector.
2. Separate forward of parent aircraft by means of booster rockets.
3. At booster burnout, (store approximately 300 feet ahead of parent aircraft) constant 3 1/2 $^{\circ}$ up elevator applied
4. When flight path angle reaches 270°, apply 0° elevator and hold for a vertical descent terminal trajectory.

This program was developed and studied on an analog computor and was found to be relatively insensitive to variations in launch altitude, temperature and airspeed. For a total of 27 launch conditions (shown in Table I) the average horizontal distance from launch point to terminal trajectory was down range approximately 600 feet. The probable error for the group was within 200 feet of this average.

Discussion with operational personnel in the Armed Services revealed a strong desire to launch over the target rather than up range

from the target. Consequently a study was made to determine the feasibility of modifying the flight path to allow launching over the target. This report presents the results of that study.

2.0 METHOD OF APPROACH

To move the terminal trajectory up range, the most obvious approach would be to use some other elevator setting. However, the 3 1/2° setting selected from the Phase I studies appears to be an optimum; that is, for a family of constant elevator settings, 3 1/2° results in the farthest up range terminal trajectory. Hence, other factors remaining the same, no further improvement can be expected using constant elevator settings.

Another approach would be to initiate the pull-up sooner, allowing less separation distance ahead of the parent aircraft, and thus shifting the entire trajectory up range. This, however, would sacrifice separation distance, and, therefore, reduce the safety of the system. During launch and separation, the time the booster rockets are burning, the store is automatically stabilized and trimmed to its launch attitude in space. Such stabilization will compensate for any rocket misalignments which are likely to be encountered. When the pull-up is initiated, the pitch stabilization becomes inoperative. In the original system, pull-up occurs after burnout so that any rocket misalignments have been trimmed out during the operative period of the stabilization system. However, if pull-up is initiated prior to burnout, rocket misalignments would be untrimmed during the latter portion of the rocket burning time and could affect the entire trajectory.

Upon inspection of a typical constant elevator trajectory, it is

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noticed that the flight path radius decreases during the constant elevator maneuver. It is readily apparent that the terminal trajectory would move up range if the loop were more nearly circular. This could be accomplished by a multi-step elevator program. Bearing in mind the desire for simplicity it was decided to see what could be done with a two-step elevator program. Using the 3 1/2° constant elevator trajectories as a guide, it was decided to modify by using increased elevator deflection for the first quadrant of the trajectory and decreased deflection for the second and third quadrants. In this manner the flight path would have decreased radius for the first quadrant and increased radius for the second and third quadrants thereby moving the terminal trajectory up range.

3.0 RESULTS

The following programs were investigated on an analog computor and compared for the 27 launch conditions listed in Table I.

Constant Elevator Program

1. Eject downward from parent aircraft.
2. Fire booster rockets for forward separation from parent aircraft.
3. At booster burnout (approximately 300 feet separation from parent aircraft) apply 3 1/2° up elevator and hold.
4. When pitch angle, θ, equals 280°, (flight path angle, γ, approximately 270°) reduce elevator to 0° and hold for vertical descent terminal trajectory.

Two-Step Elevator Program

1. Eject downward from parent aircraft.
2. Fire booster rockets for forward separation from

parent aircraft.

3. At booster burnout (approximately 300 feet separation from parent aircraft) apply 4° up elevator and hold.

4. When pitch angle, θ, equals 100°, ($\gamma = 90^{\circ}$) reduce elevator to 3° and hold.

5. When pitch angle, θ, equals 280°, ($\gamma = 270^{\circ}$) reduce elevator to 0° and hold for vertical descent terminal trajectory.

Steps 1 and 2, launch and separation, had previously been run on an IBM Type 650 digital computor. Output conditions from the digital computor constituted the input conditions for the analog which took over at Step 3. For any given set of launch conditions both programs completed the loop in essentially the same amount of time, which for all conditions was more than 20 seconds. During the trajectory studies, the pitch angle at which the elevator deflection is reduced from 4° to 3° was varied approximately 15° either side of the intended 100°. The maximum resulting variation in terminal trajectory location was 100 feet.

Figure 1 shows the distribution of terminal trajectories for both programs throughout the range of launch conditions. On the average, the two-step-elevator trajectories terminated 634 feet up range from the launch point. The probable error from this average was 173 feet. The constant elevator trajectories terminated an average 600 feet down range with a probable error of 198 feet. Figures 2 through 8 present 7 trajectory profiles from a representative sampling of the launch conditions of Table I. For comparison, both the constant elevator and two-step elevator programs are shown in each figure. Figures 2, 5, and 8 illustrate the effects of launch altitude for medium launch Mach No.

on a Standard day. Figures 4, 5, and 6 illustrate the effects of launch Mach No. at medium launch altitude on a Standard day. Figures 3 and 7 illustrate the 2 extremes in loop size. Figure 3 corresponds to launch conditions of high altitude, high temperature and high Mach No., while Figure 7 corresponds to launch conditions of low altitude, low temperature, and low Mach No.

4.0 CONCLUSIONS

It is concluded that the study presented herein clearly illustrates the feasibility of using a 2-step elevator program to bring about an up-range shift of the terminal trajectory. It is apparent that the terminal trajectory can be located anywhere within the range bracketed by the two programs by varying the elevator settings used.

TABLE I

Launch Conditions for Trajectory Studies

Ryan Model 109G

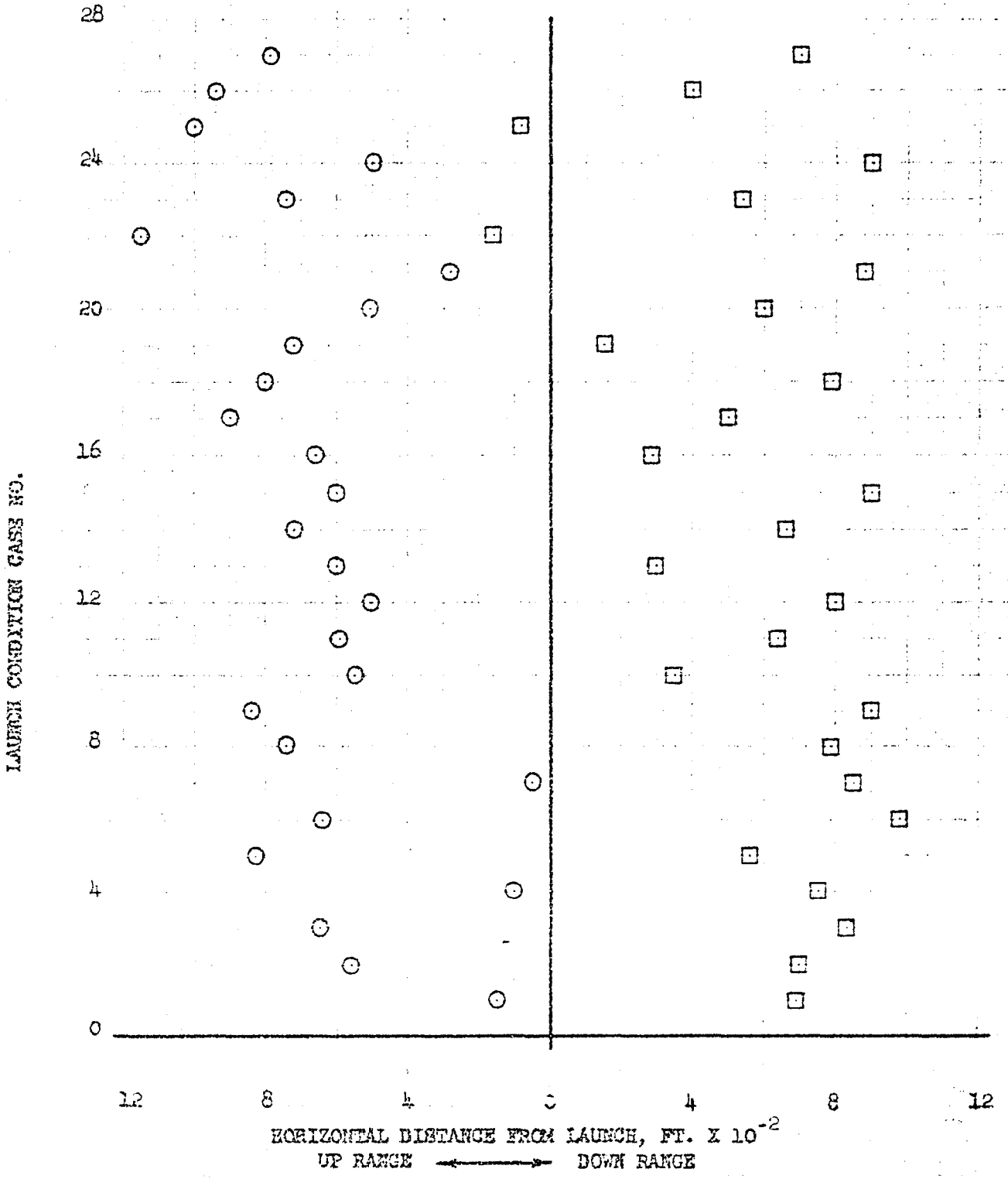
Case No.	Altitude	Temperature	Mach No.
1	7000 ft.	Cold Day	0.70
2	"	" "	0.85
3	"	" "	0.95
4	"	Std. Day	0.70
* 5	"	" "	0.85
6	"	" "	0.95
7	"	Hot Day	0.70
8	"	" "	0.85
* 9	"	" "	0.95
10	3500 ft.	Cold Day	0.70
11	"	" "	0.85
12	"	" "	0.95
* 13	"	Std. Day	0.70
* 14	"	" "	0.85
* 15	"	" "	0.95
16	"	Hot Day	0.70
17	"	" "	0.85
18	"	" "	0.95
* 19	50 ft.	Cold Day	0.70
20	"	" "	0.85
21	"	" "	0.95
22	"	Std. Day	0.70
* 23	"	" "	0.85
24	"	" "	0.95
25	"	Hot Day	0.70
26	"	" "	0.85
27	"	" "	0.95

* Corresponding Trajectories Shown Herein.

RYAN MODEL 109G

Figure 1

TERMINAL TRAJECTORY LOCATIONS FOR 27 LAUNCH CONDITIONS



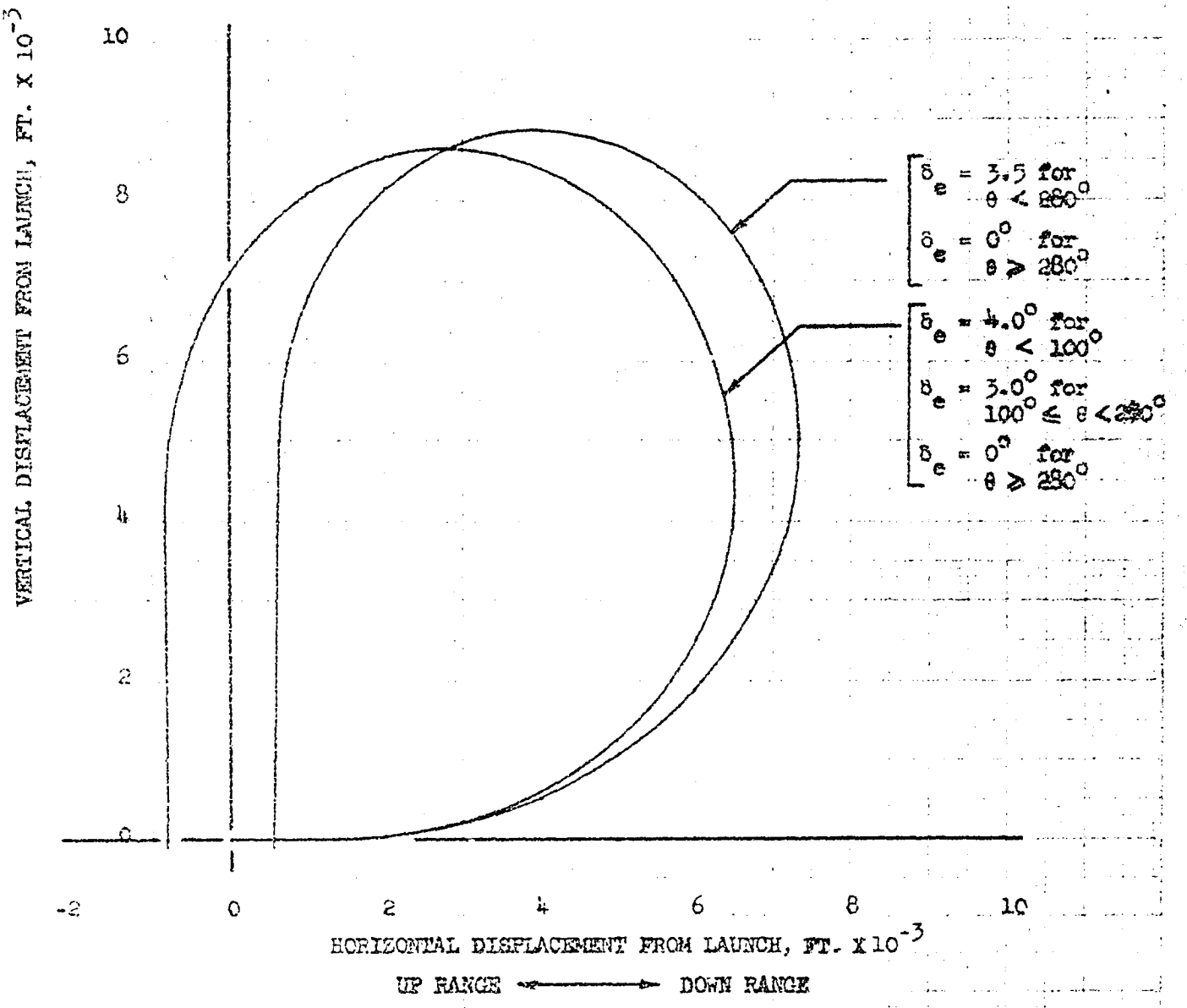
RYAN MODEL 109G

Figure 2

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt. 7000 ft.
Temp. Std.
Mach. No. 0.85



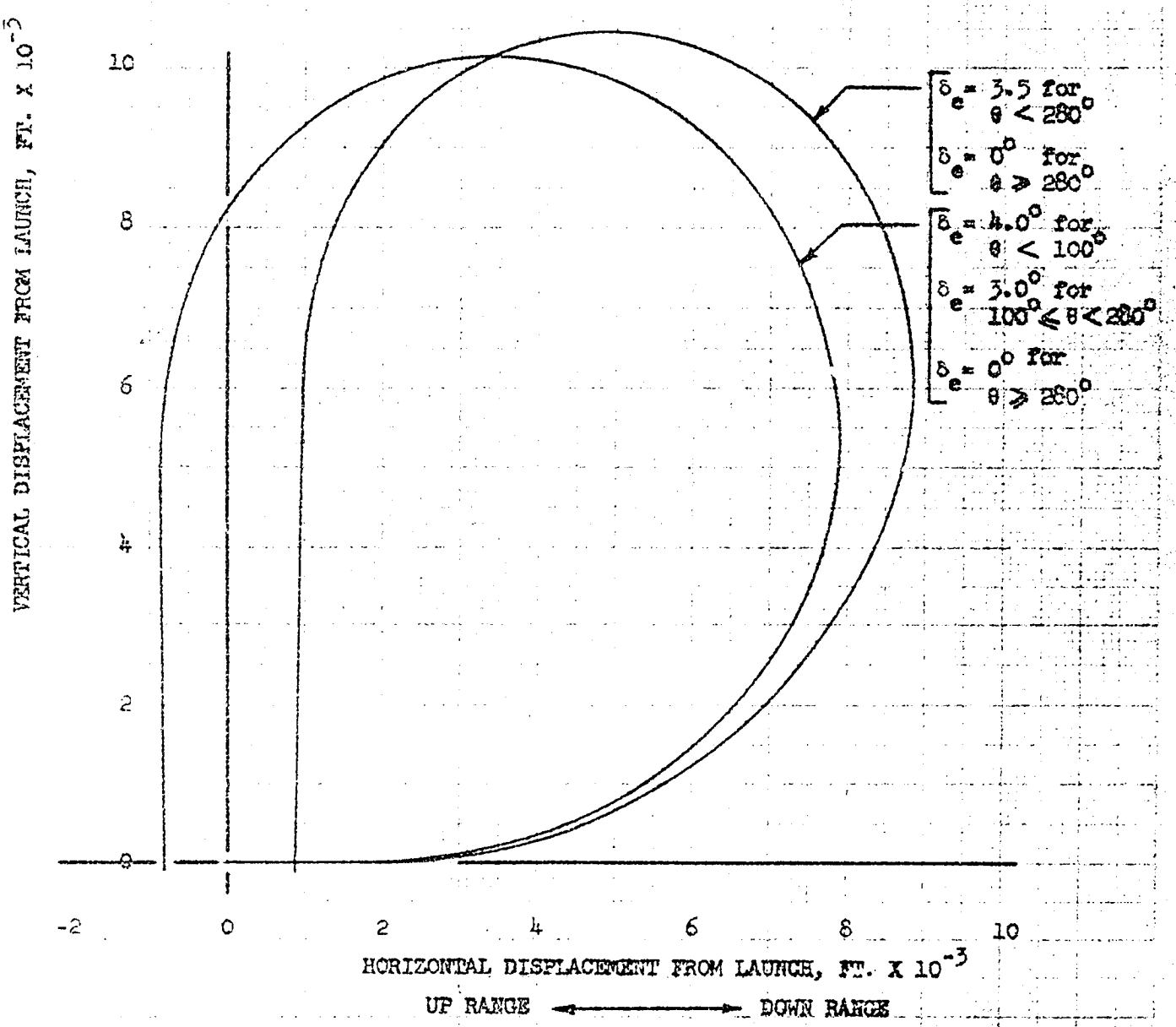
RYAN MODEL 109G

Figure 3

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt.	7000 ft.
Temp.	Hot
Mach No.	0.95



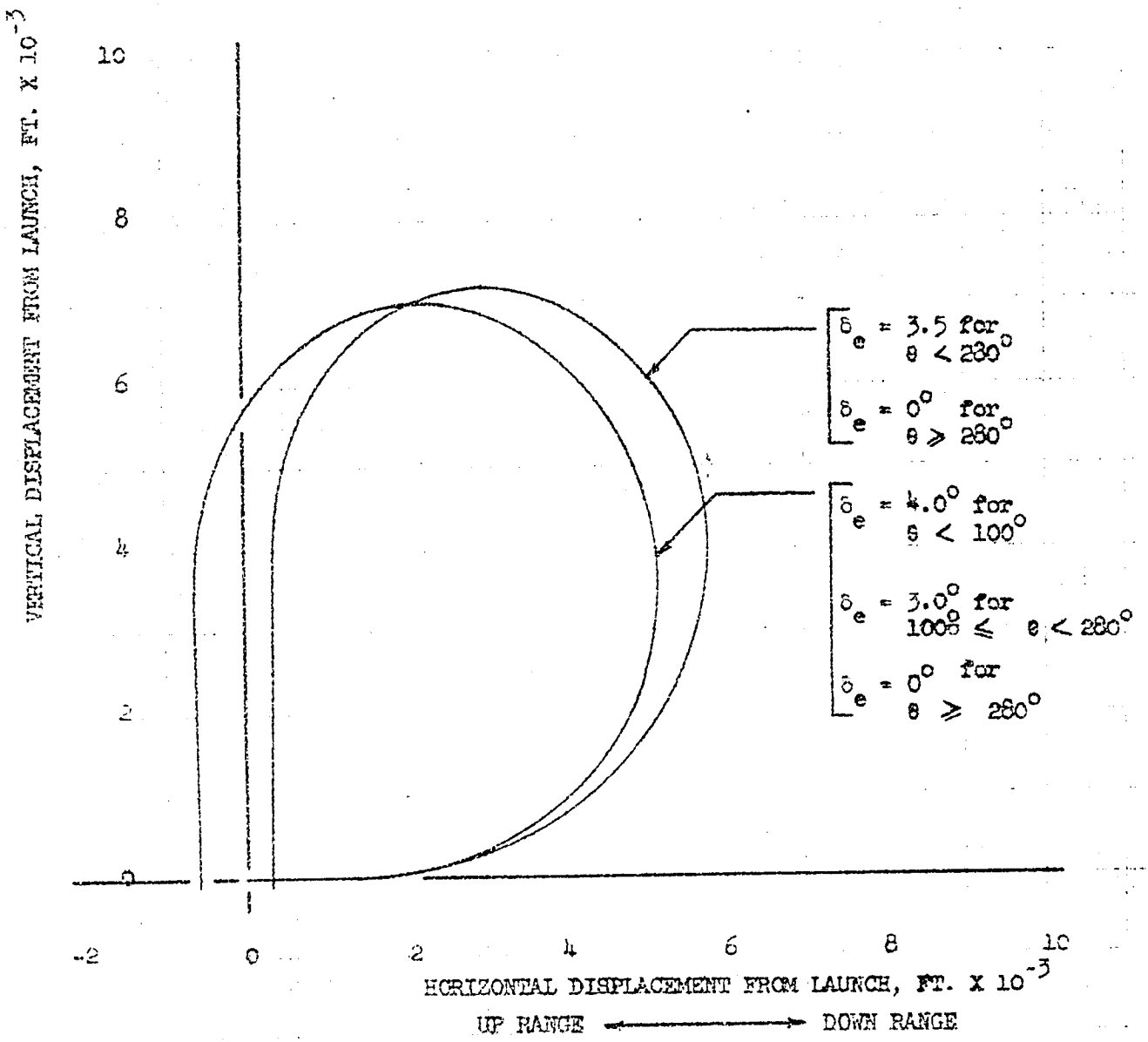
RYAN MODEL 109G

Figure 4

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt.	3500 ft.
Temp.	Std.
Mach No.	0.70



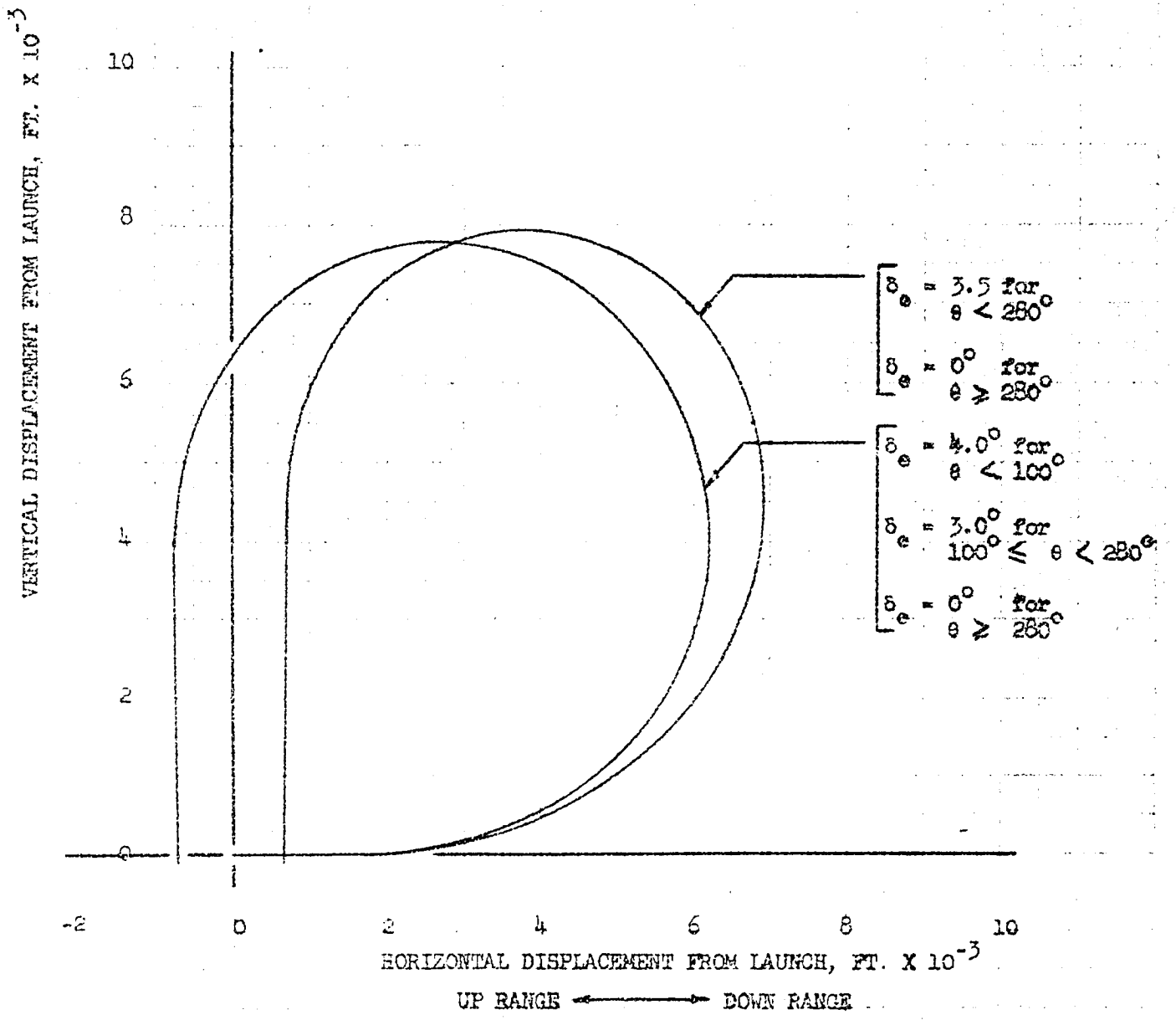
RYAN MODEL 109G

Figure 5

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt.	3500 ft.
Temp.	Std.
Mach No.	0.85



RYAN MODEL 109G

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

Figure 6

LAUNCH CONDITIONS

Alt.	3500 ft.
Temp.	Std.
Mach No.	0.95

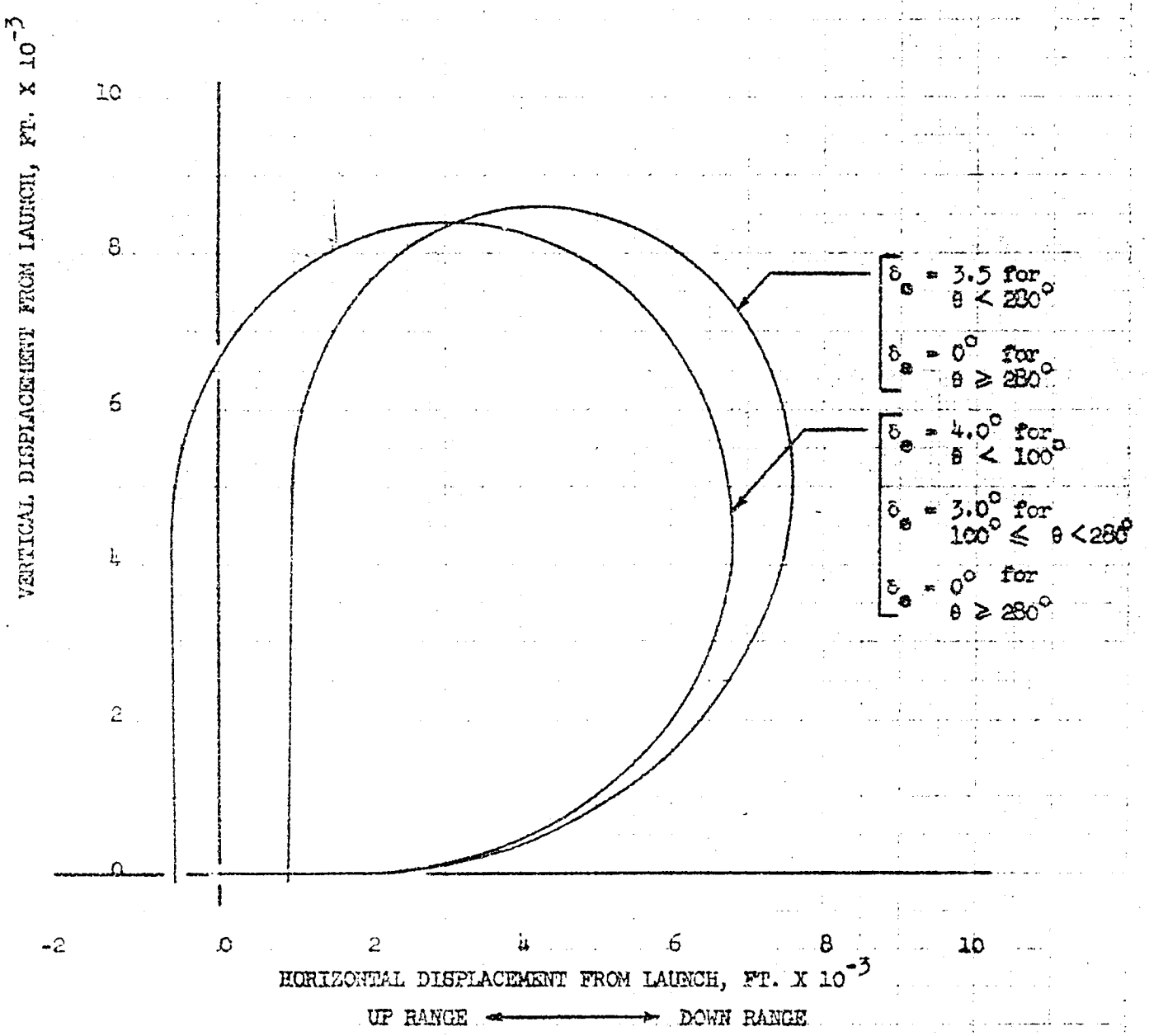


Figure 7

RYAN MODEL 109G

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt.	50 ft.
Temp.	Cold
Mach No.	0.70

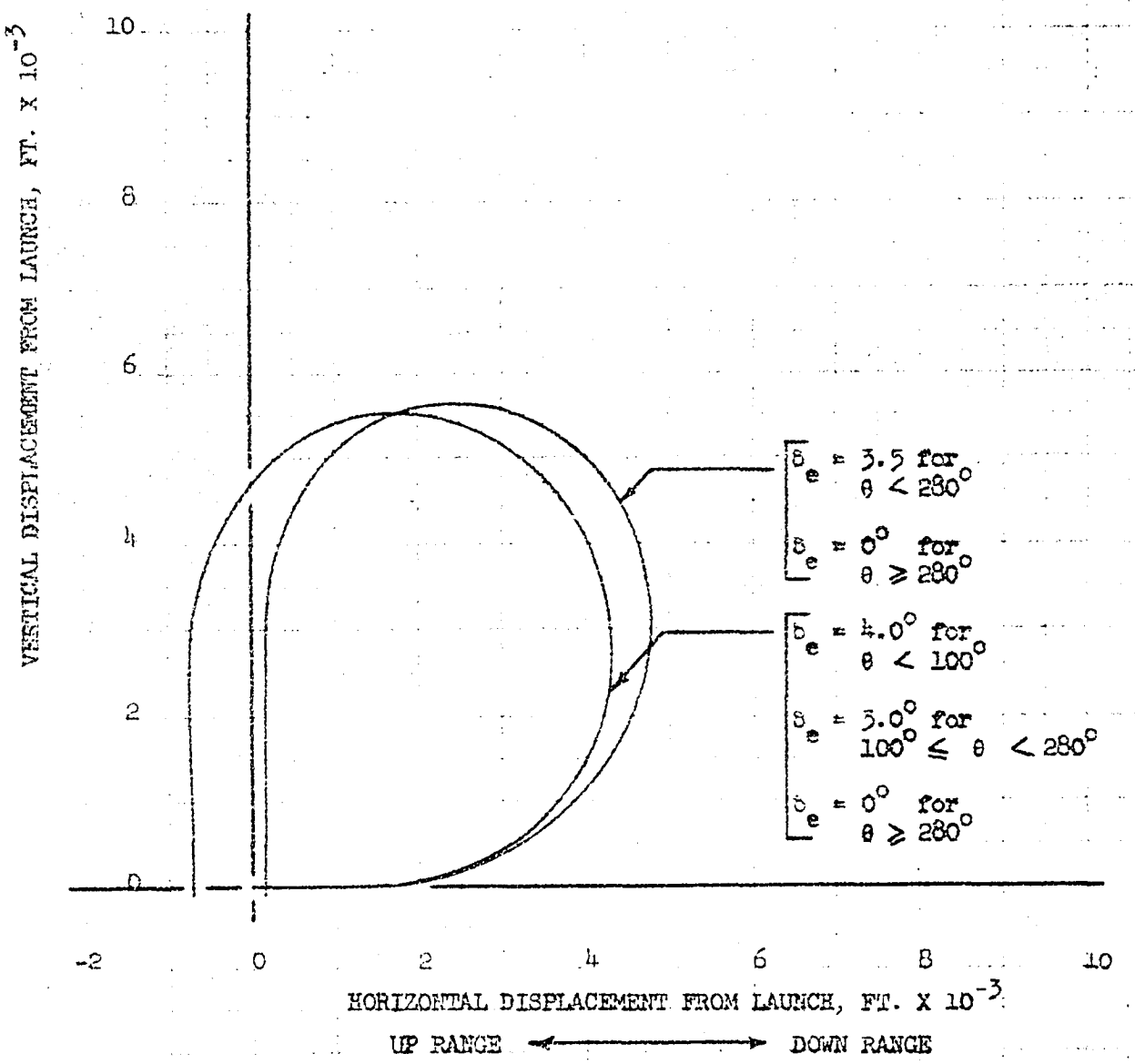


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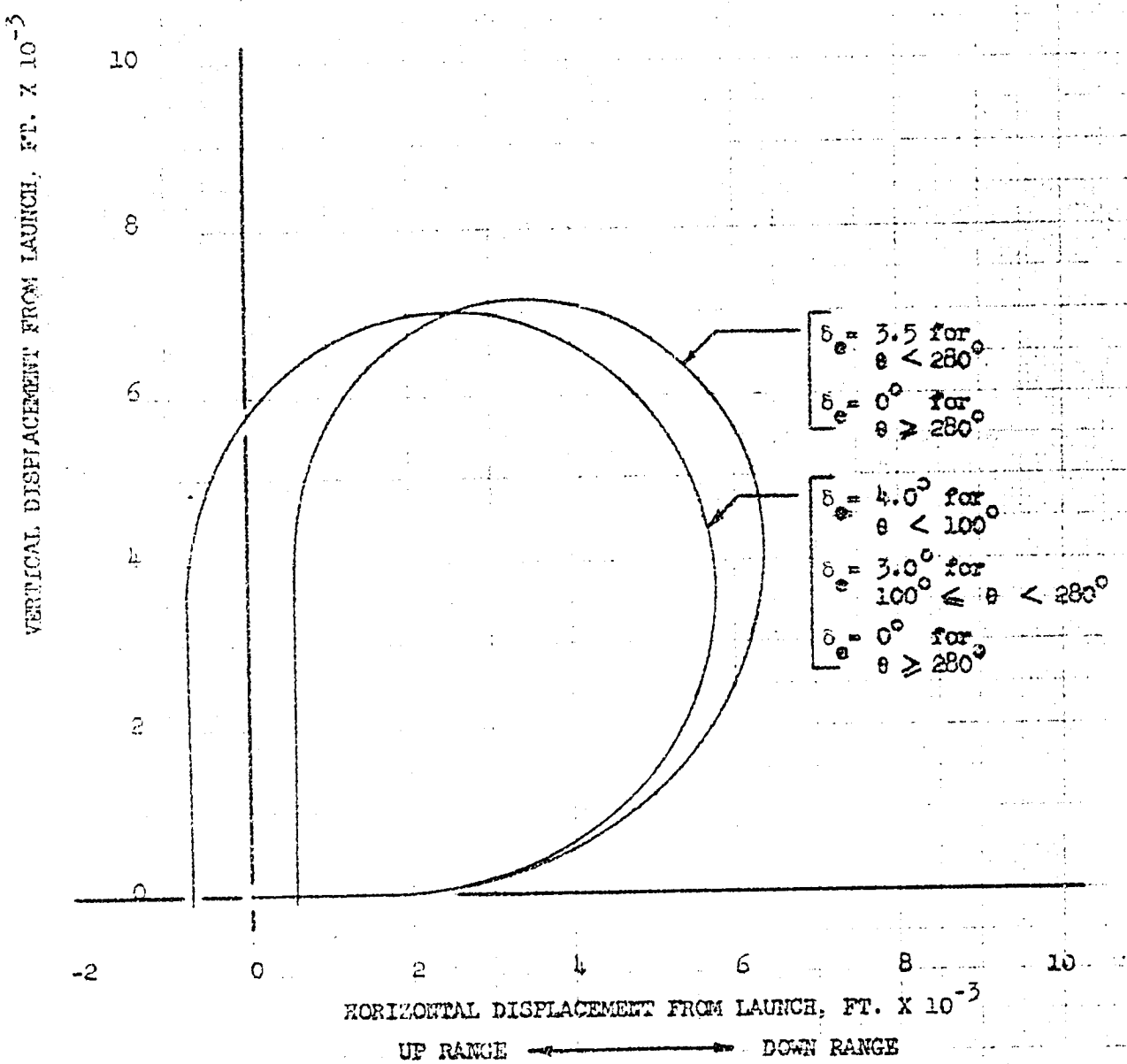
Figure 8

TRAJECTORY PROFILES FOR TWO ELEVATOR PROGRAMS

LAUNCH CONDITIONS

Alt.	50 ft.
Temp.	Std.
Mach No.	0.85



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