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SOME EFFECTS OF DESCENT ENGINE THROTTLE LOGIC AND INITIAL ALTITUDE ERRORS ON LANDING SITE VISIBILITY

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SUMMARY

A number of runs performed on the MSC/GCD hybrid landing simulation are reviewed to determine some effects of descent engine throttling logic and initial altitude errors on post high gate landing site visibility. Two throttling logics were considered following the initial throttle down (1) the engine thrust command was limited to a maximum value near 60%, or (2) the engine was returned to the 92½% constant throttle if the LGC thrust command exceeded a certain value. The study indicated that during certain test conditions logic (1) produced detrimental effects on post high gate visibility and logic (2) produced thrust pulses that could be operationally undesirable disturbances.

INTRODUCTION

The LM descent guidance is designed to operate with the descent engine limitation of not being able to throttle between 60 and 92.5% throttle setting. The guidance operates by commanding the descent engine to a constant throttle (92½%) for the major portion of the braking phase until the computed thrust command (T_c) goes to a level lower than 60%. The engine is then throttled to T_c. If the thrust output follows T_c from the throttle point to high gate, then the high gate aim point conditions should be achieved, and proper visibility of the landing site after high gate should be attained.

The problem of interest is the possibility of T_c returning to the 60-92.5% region after the initial throttle down because of radar updating of the LGC estimate of altitude. The two choices of logic following the initial throttling are to command the engine back to the constant 92½% until T_c again returns to less than 60% (rethrottle logic), or to limit the engine command to less than 60% (limit logic). The DPS is capable of handling the thrust pulses generated by the rethrottle logic, provided the pulses are at least one second duration (ref 1). The pulses, though, might be operationally undesirable. The limit logic prevents these thrust pulses, but can cause the high gate conditons to be missed for some cases, affecting landing site visibility after high gate.

This report presents a comparison of the effect of throttling logic and altitude errors on post high gate visibility. The data of this report were obtained from studies made on the GCD hybrid landing simulation where throttling logic was not the primary item under consideration. Therefore, these data merely show some of the possible effects of throttling logic and the report is presented to show that problems do exist and to indicate the conditions under which these problems were encountered.

DESCRIPTION OF SIMULATION

The simulation was first described in reference 2. The guidance logic contained in the simulation was the logic as presented in reference 3 with the following exceptions:

Time to Go Equation - The equation obtained from A. Klumpp (MIT) via telephone on July 14, 1966, shown in figure 1, was used in the simulation.

The greater accuracy of this equation enables the acceleration to be computed for T_{go} greater or equal to 10 seconds from high gate.

Acceleration Computation Schedule - The acceleration command was computed every 2 seconds (until 10 sec from high gate), and in-between the 2 second intervals the command to the vehicle was changed every $\frac{1}{4}$ second by extrapolating between the computed command and desired acceleration at the aim point.

Radar Updates - The LGC altitude was updated according to the update schedule and linear uncoupled weighting function presented in reference 4. The radar altitude acquisition occurred at an LGC indicated altitude of 24,000 feet. The terrain was assumed to be smooth, but an altitude difference between the terrain and LGC estimate was assumed to exist at the radar acquisition altitude.

Throttle Logic - The logics A & B of table I were used.

Constant Throttle Thrust Profiles - An engine thrust profile of +2% was used ($T = (9845 + 1.48t)$ lbs. where t+0 at the start of the full thrust descent). The aim points were adjusted so that a throttle down time of 110/sec (T_{go} to high gate) occurred for the +2% profile.

Trajectory - The initial conditions and guidance aim points are shown on table II. Rows II & III were used in the simulation. Row I was the original MIT trajectory which was designed for a $\pm 1\%$ thrust uncertainty. This trajectory was changed to II & III for $\pm 2\%$ thrust uncertainty by shifting all the aimpoints 20,000 ft. down range, but maintaining the same desired altitude. Trajectory III also lowered the desired thrust level at high gate.

Test Runs - The six runs presented consist of a descent with no altitude error, an altitude error of vehicle high 3,000 feet and vehicle low 3,000 feet with throttle logics A & B, and then a change of aim point conditions from II to III for vehicle low 3,000 feet for logic B.

DISCUSSION OF RESULTS

The no altitude error condition is shown on figure 2. The thrust has no tendency to return to the non-throttleable region after the initial throttle down point (335 seconds). The high gate conditions were attained and the visibility following high gate was satisfactory.

The worst condition encountered is shown on figure 3 for a vehicle high condition with the limit logic (A). At 390/sec the thrust command went up to 57% and then continued to build up because the engine command was limited. The low thrust prevented the spacecraft from achieving the high gate desired conditions as evident from the effect on the LPD profile after high gate. The landing site remained below the bottom of the LM window (no visibility) for 30 seconds after high gate. The same case had a nominal visibility profile after high gate when the rethrottle logic (B) was used (figure 4). Four thrust pulses occurred before high gate.

The same results were obtained with logics A & B for a vehicle low condition as shown by comparing figures 5 and 6 with figures 3 and 4. For logic A, the effect on visibility was not as bad as for the vehicle high condition as the target was visible after high gate. More thrust pulses were required, though, to reach the high gate conditions for the rethrottle logic.

The thrust pulses shown on figure 6 have violated the criteria of at least one second duration as stated in the introduction. This is evident from the two pulses that did not reach the full thrust level. This was a result of changing the commanded acceleration at $\frac{1}{4}$ second intervals in the simulation. Had the acceleration command been held constant over the two second intervals, which is the current plan, then the pulses would have had a minimum duration of two seconds.

The desired thrust at high gate (56.5%), for the case of figure 6, is near the throttle logic test point (58%). The number of thrust pulses that occurred for the condition of figure 6 was reduced by half, as is shown on figure 7, by lowering the desired thrust at high gate (aim points III). Therefore, it may be possible with a proper choice of aim point conditions and throttle logic to eliminate the pulses altogether. It is possible the throttle logic shown as item C on table I would do this. Another possibility would be to make the minimum throttle pulse time longer, e.g., 5 to 10 sec so that not more than one pulse would ever be likely to occur. This could be done by adding a time delay such that the engine could not automatically be throttled down for t sec. after being throttled up again. Further simulations are required to examine specific cases.

CONCLUSIONS

For the trajectory conditions studied, detrimental effects on the visibility phase of LM descent were found when the descent engine thrust command was limited after initial entry into the throttling region. The effects were greatest for a vehicle high condition.

The detrimental effects on post high gate visibility were eliminated by allowing the descent engine to rethrottle back to the constant 92½% thrust command if the LGC thrust command exceeded a certain value. The result is a number of thrust pulses that might be undesirable operationally.

For either the limited thrust command or rethrottle capability, the detrimental effects can probably be reduced or eliminated by selection of high gate conditions to reduce the desired thrust at high gate or by adding hysteresis in the throttle logic. A ΔV penalty would probably be associated with a lower desired thrust at high gate to completely eliminate the detrimental effects. Further studies are required to evaluate these problems and possible solutions.

REFERENCES

1. MSC Memorandum (EP2 to EG23), "LM DPS Throttling Logic," C. H. Lambert, Jr., Nov. 2, 1966

2. MSC/GCD Memorandum, EG27-3-66, "Presimulation Report - Piloted Lunar Landing Simulation Using A Math Model LM Guidance Computer," T. E. Moore, Jan. 11, 1966

3. MIT Report E-1981, "LM - PGNCS Guidance Equations for a Nominal Lunar Landing Mission", N. E. Sears, P. F. Hoffman, May 2, 1966

4. MIT Report E-1982, "LM PGNCS and Landing Radar Operations During the Powered Lunar Landing Maneuver," B. Kriegsman, N. Sears, August, 1966

A	Engine Command From Constant throttle $92\frac{1}{2}\%$ to Thrust Command (T_c) when $T_c < 51\frac{1}{2}\%$, after which engine command limited to 57% if $T_c > 57\%$
B	$92\frac{1}{2}\%$ to T_c when $T_c < 58\%$ T_c to $92\frac{1}{2}\%$ when $T_c > 58\%$
C	$92\frac{1}{2}\%$ to T_c when $T_c < 50\%$ T_c to $92\frac{1}{2}\%$ when $T_c > 58\%$

Table I - Throttle Logic

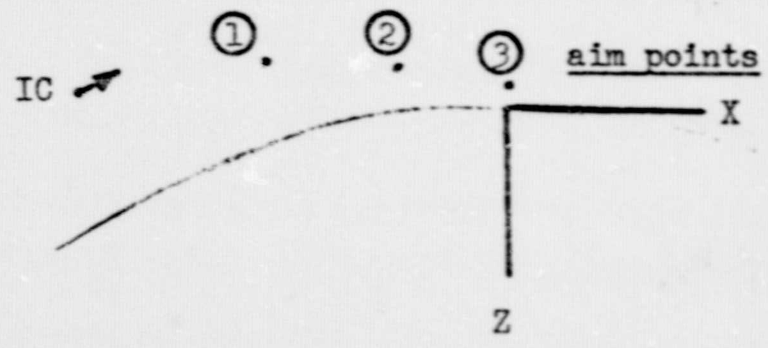
Initial Conditions

$X = -1{,}366{,}404$ Ft. $\quad Y = 0 \quad Z = +114{,}212$

$\dot{X} = 5407 \quad \dot{Y} = 0 \quad \dot{Z} = -1319$

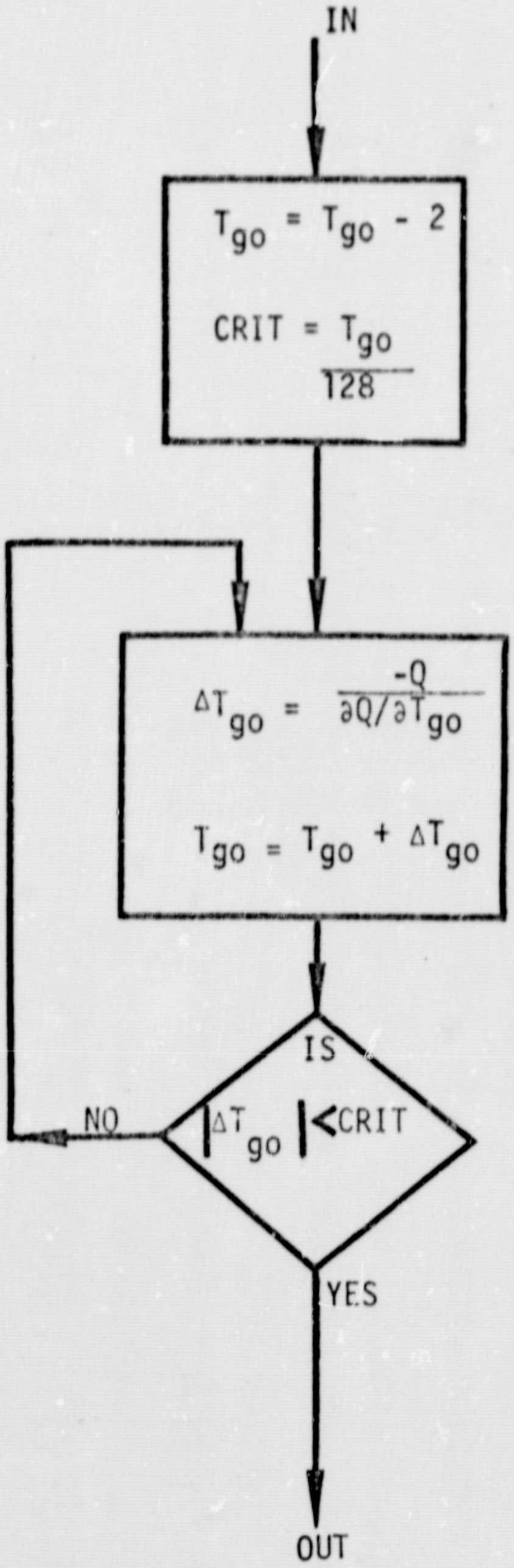
$\theta = 101.3 \quad W = 32052$ Lbs.

Landing Site Coordinate System
(non-rotating moon)



COMMENTS	AIM POINT	DESIRED AIM POINT CONDITIONS						
		X_D	Z_D	$\dot{X}_D$	$\dot{Z}_D$	$\ddot{X}_D$	$\ddot{Z}_D$	$\dddot{X}_D$
I. Original MIT Trajectory #423818, 7/6/66 for $\pm1\%$ Thrust Uncertainty and 56.5% Td at High Gate	(1) False	-88229	-15719	1139	87.3	-14.8	-1.58	-.0165
	(2) High Gate	-42013	-9711	705	151	-8.97	+1.144	-.0110
	(3) Hover	-3	-115	2.5	1.4	-1.25	-0.7	+.0735
II. Changes to (I) for $\pm2\%$ T_E (Maint. 56.5% Td @ h.g.)	(1) False	-68229	-15993	1139	87.3	-14.8	-1.58	-.0165
	(2) High Gate	-22013	-9823	705	151	-8.97	+1.144	-.0110
	(3) Hover	+19997	-80	2.5	1.4	-1.25	-0.7	+.0735
III. Changes to (I) for $\pm2\%$ T_E and 52% Td at High Gate	(1) False	-68229	-15993	1139	87.3	-14.8	-1.58	-.0165
	(2) High Gate	-23013	-9827	705	140	-8.25	+1.48	-.0110
	(3) Hover	+19997	-80	2.5	1.4	-1.25	-0.7	+.0735

Table II - Trajectory Aim Point Conditions



WHERE $Q = T_{go}{}^{3}(J_D - J_f)$

J_f = PREDICTED FINAL JERK

J_D = DESIRED JERK

FIGURE 1 - FLOW CHART OF TIME TO GO SUBROUTINE.
(FROM A. KLUMPP OF M. I. T. JULY 14, 1966)

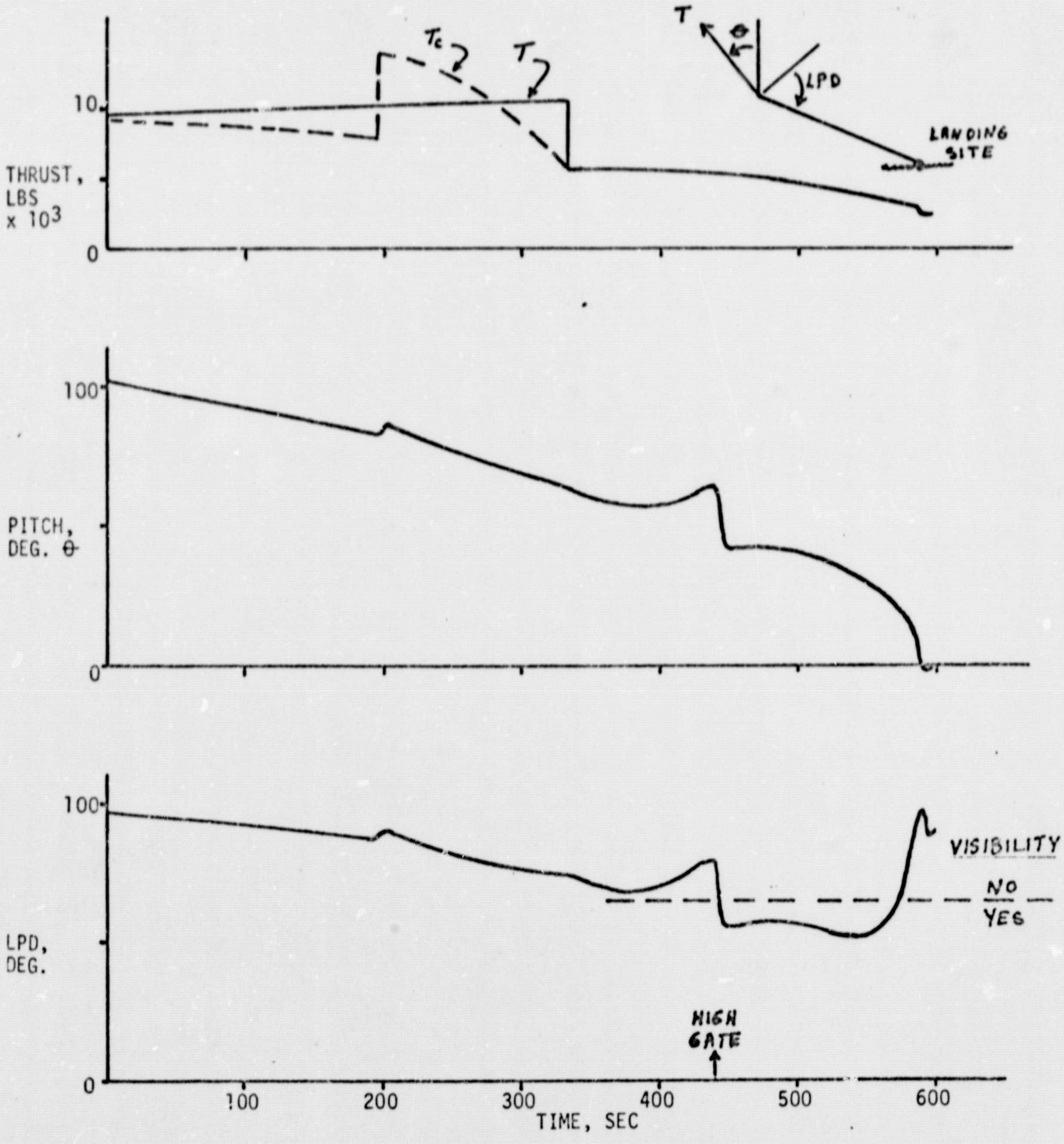


FIGURE 2 - Thrust Vector and Visibility Profiles

Run No.: 2, 9/8/66
Altitude Error : Zero
Aim Point Cond : III
Throttle Logic : B

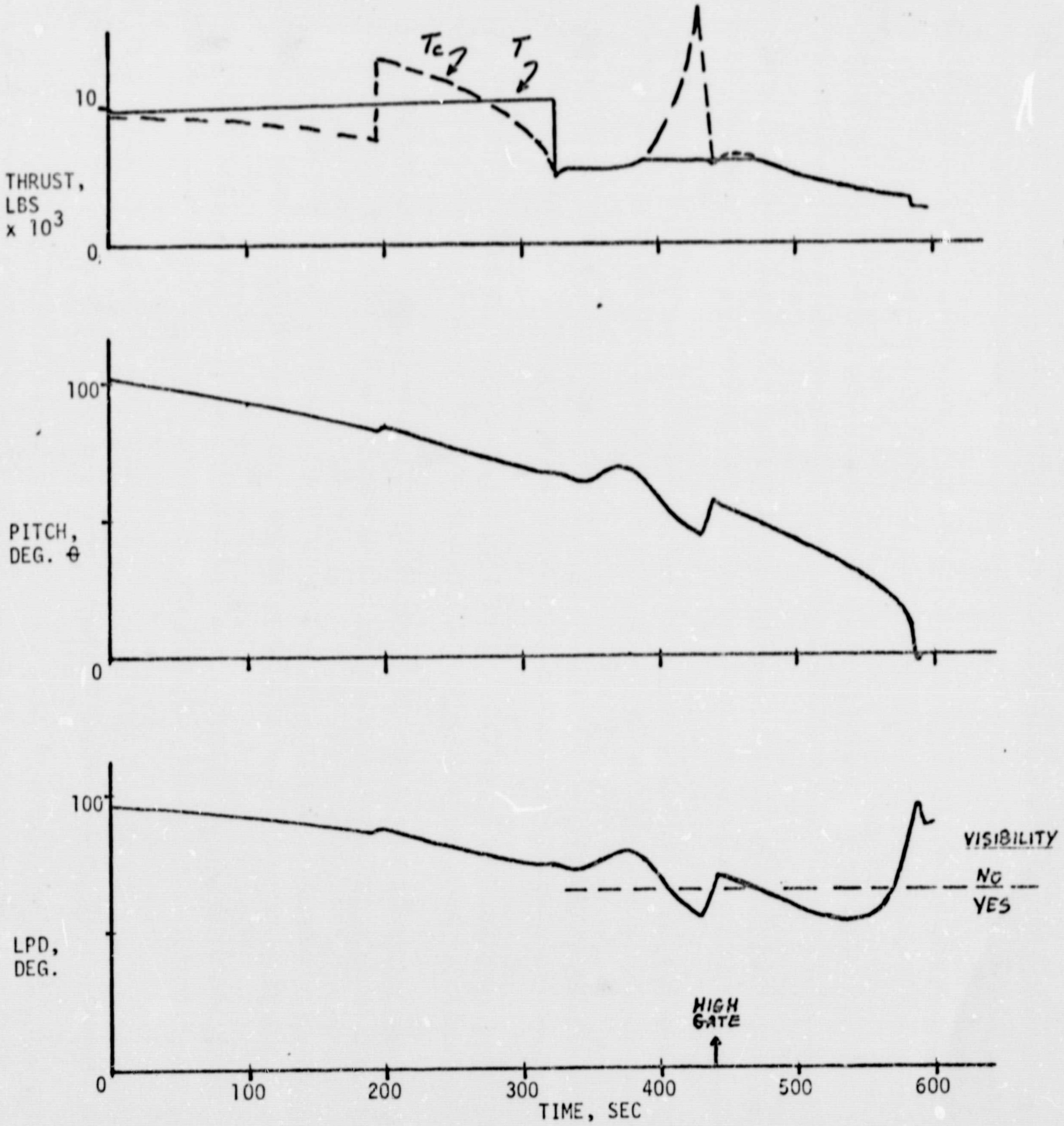


FIGURE 3 - Thrust Vector and Visibility Profiles

Run No : 3, 8/17B/66
Altitude Error : Vehicle High 3000 Ft.
Aim Point Cond : II
Throttle Logic : A

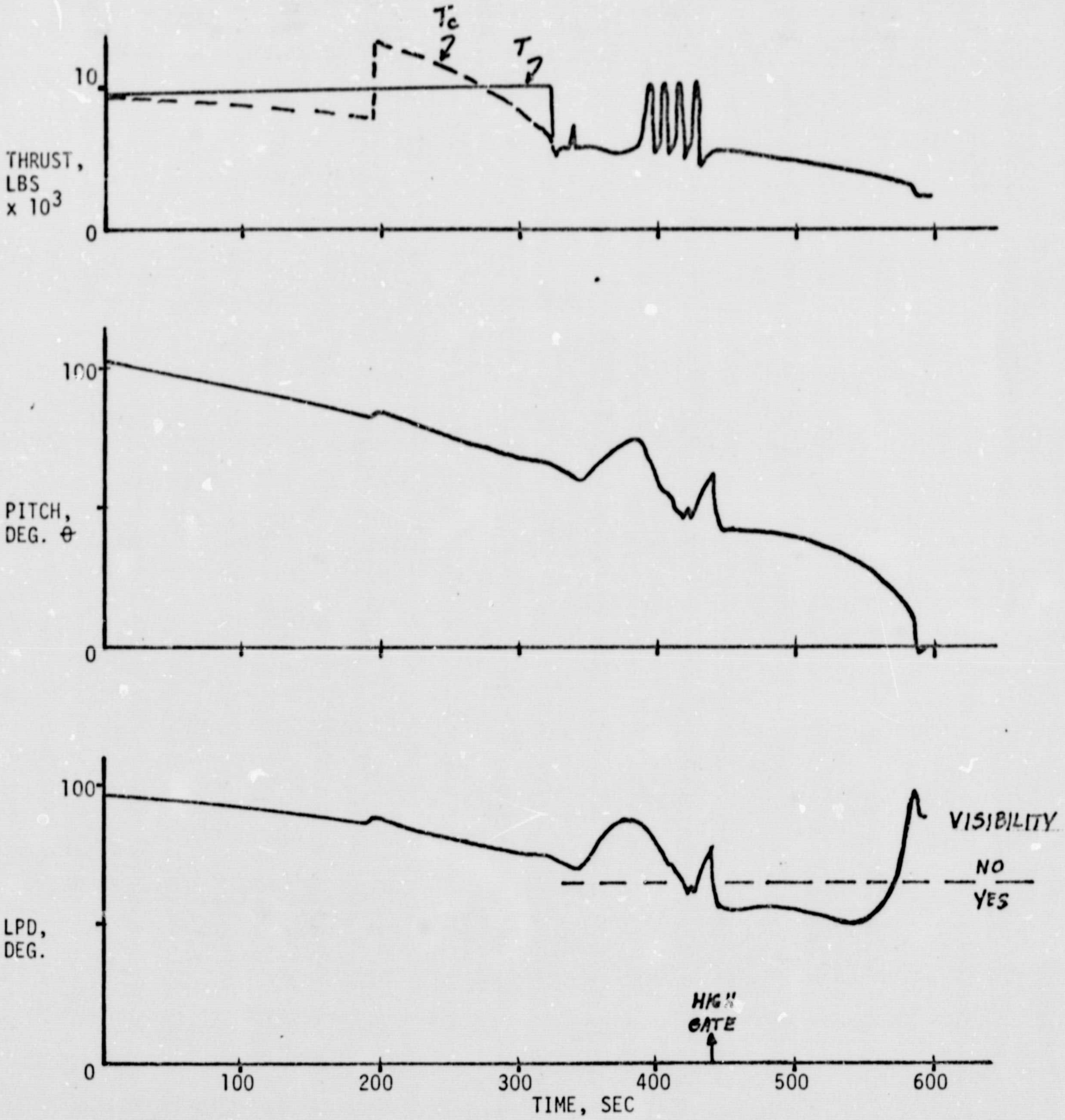


FIGURE 4 - Thrust Vector and Visibility Profiles

Run No : 3, 9/29/66
Altitude Error : Veh. High 3000 Ft.
Aim Point Cond : II
Throttle Logic : B

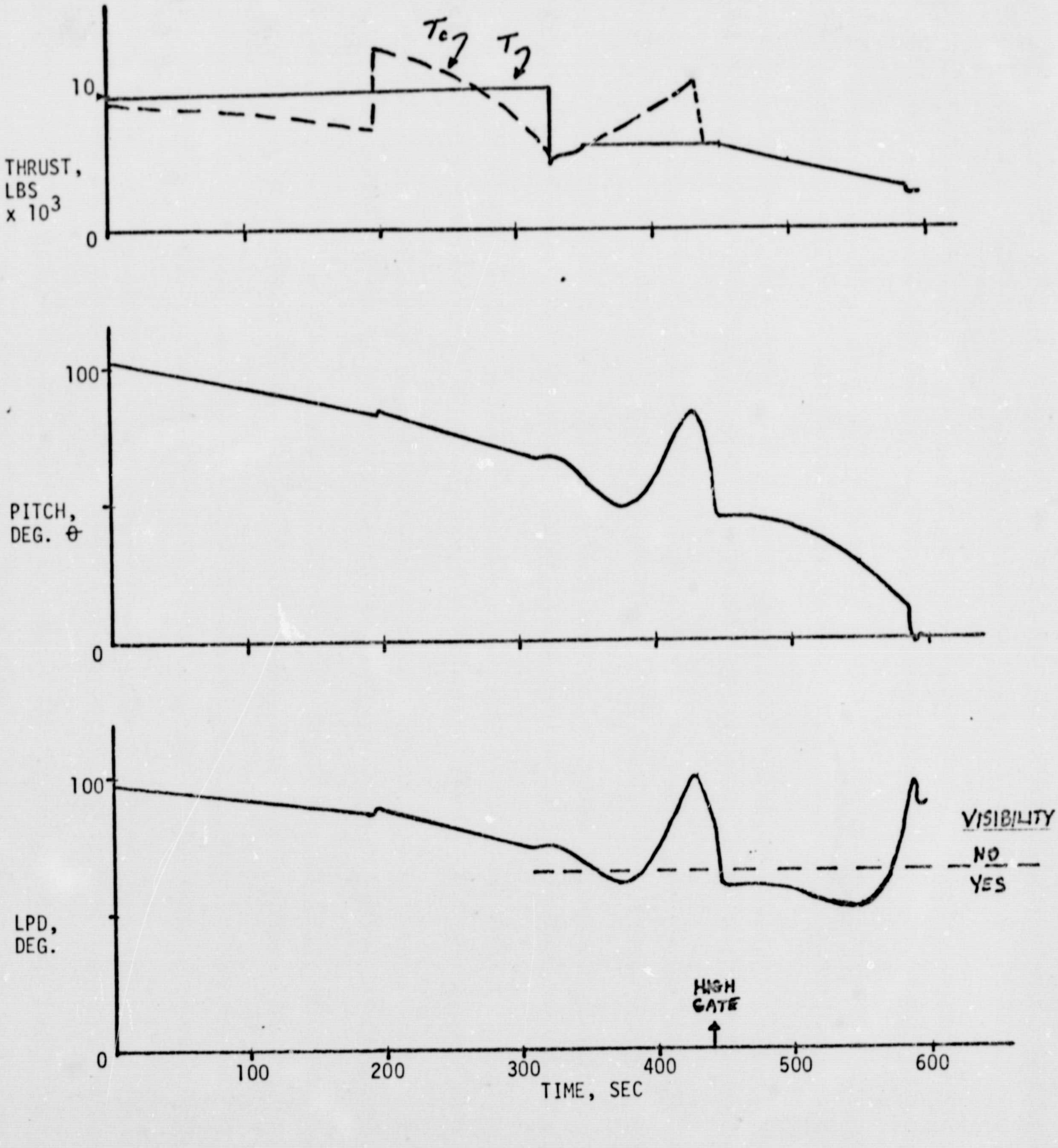


FIGURE 5 - Thrust Vector and Visibility Profiles

Run No : 4, 8/17B/66

Altitude Error : Veh. Low 3000 Ft.

Aim Point Cond : II

Throttle Logic : A

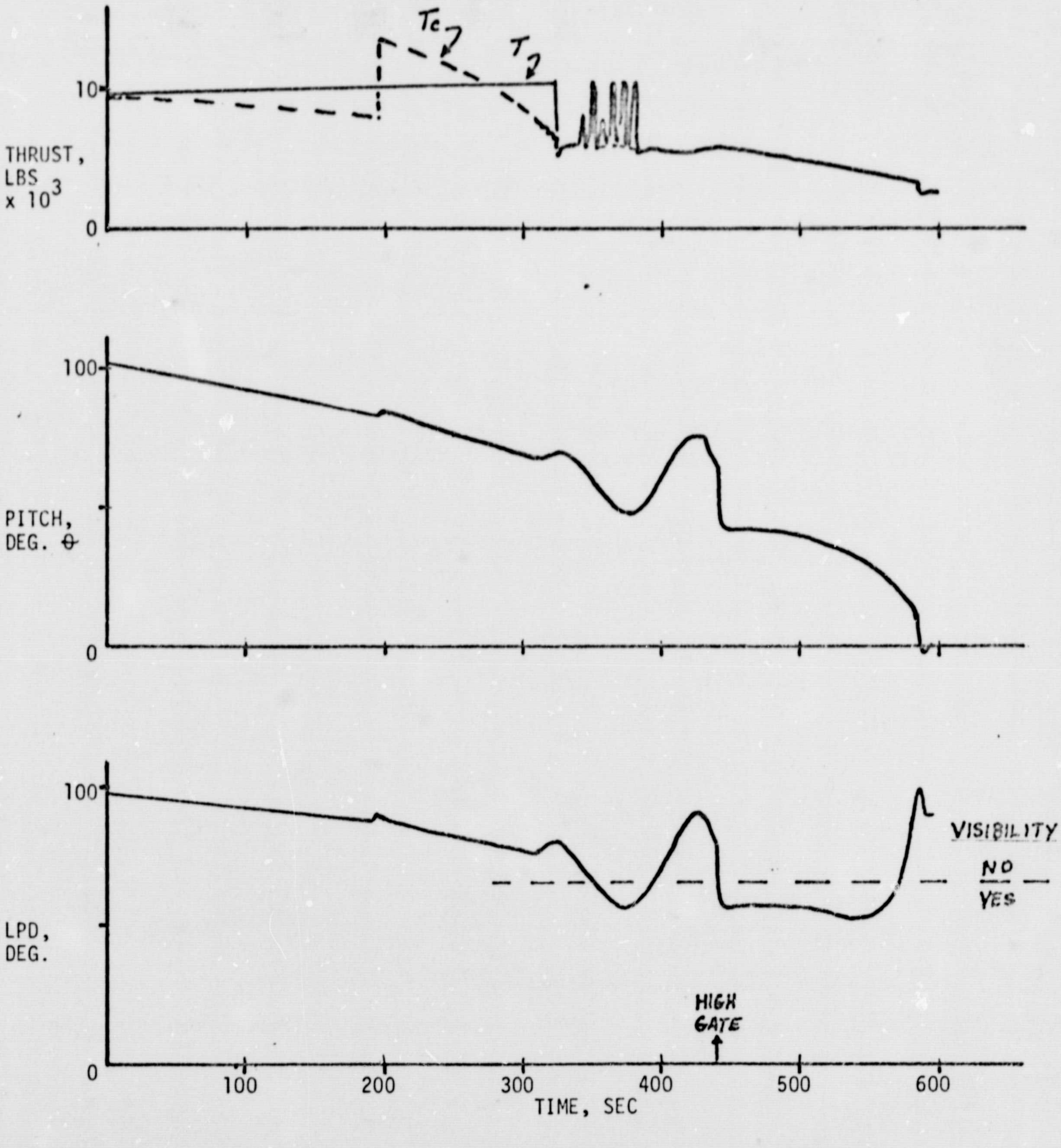


FIGURE 6 - Thrust Vector and Visibility Profiles

Run No : 4-1, 9/29/66

Altitude Error : Veh. Low 3000 Ft.

Aim Point Cond : II

Throttle Logic : B

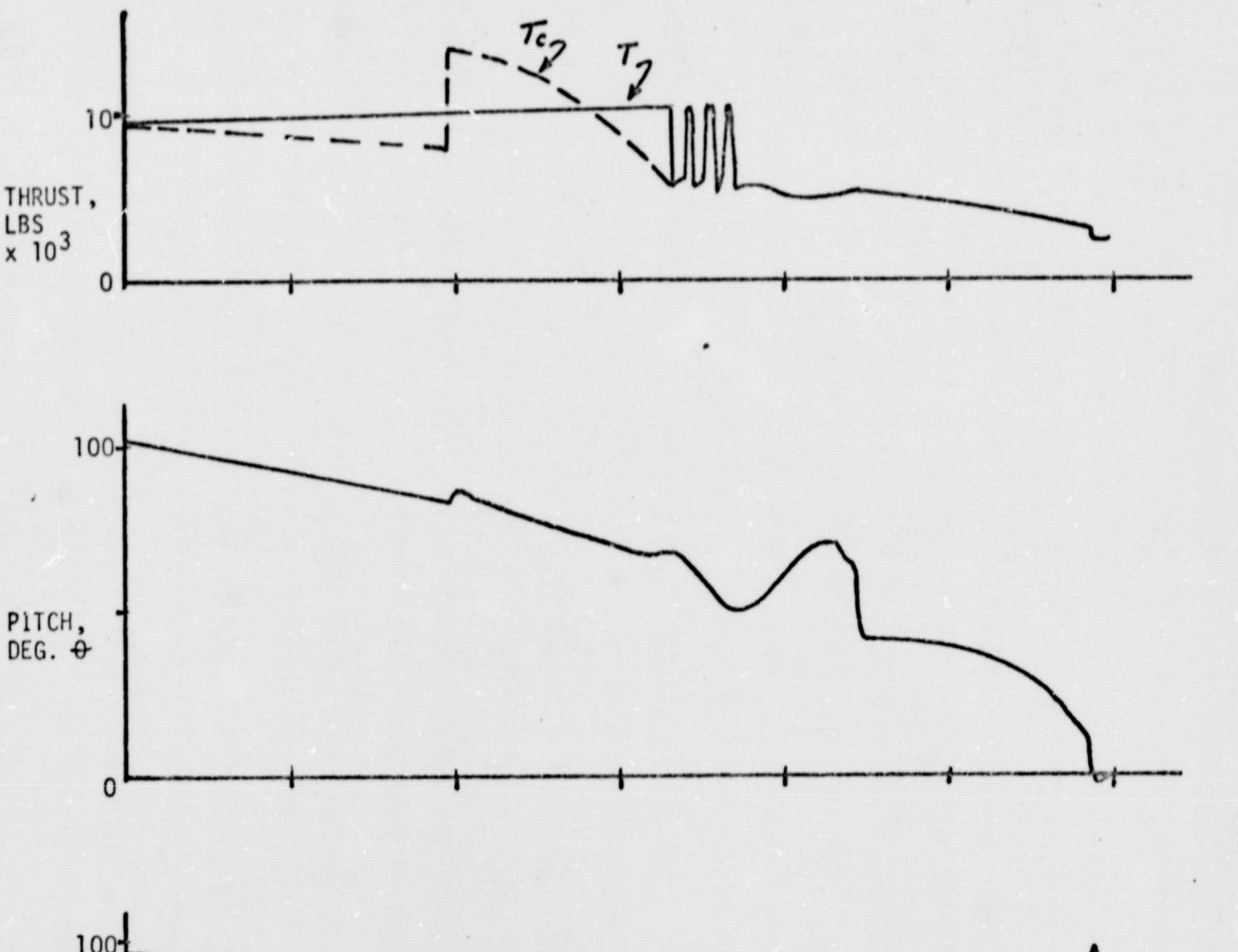


FIGURE 7 - Thrust Vector and Visibility Profiles
Run No : 4-2, 9/29/66
Altitude Error : Veh. Low 3000 Ft.
Aim Point Cond : III
Throttle Logic : B