NASA Technical Memorandum 100556

AEROASSIST FLIGHT EXPERIMENT GUIDANCE "QUIET TIME"

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(NASA-TM-100556) AEROASSIST FLIGHT EXPERIMENT GUIDANCE QUIET TIME (NASA) 78 p CSCL 22B
N88-21244
Unclas
G3/18 0140247

February 1988

National Aeronautics and
Space Administration

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Hampton, Virginia 23665-5225

ABSTRACT

The science experiments for the Aeroassist Flight Experiment (AFE) will be greatly enhanced by taking measurements with no Reaction Control System (RCS) contamination just before perigee. Methods of modifying the AFE guidance to accomplish this are discussed. Several methods that could give up to 30-seconds of "quiet time" were investigated and the results of these guidance modifications shown. A 20-second "quiet time" is definitely possible and a 30-second "quiet time" may be possible if the guidance can be inactive past perigee. Some questions that were raised during the guidance modification tests are listed; the most significant being the criterion for determining if the mission is threatened. A limited follow-on test program is outlined.

INTRODUCTION

The Aeroassisted Flight Experiment (AFE), scheduled to fly in the mid-1990's, will be used for the validation and verification of the various theories, techniques, equipment, and procedures that will be vital in any future aeroassisted orbital transfer vehicles (AOTV's) or interplanetary missions which will utilize aerocapture techniques. The AFE is a flight experiment which will use the Earth's atmosphere to assist in the dissipation of the energy required to decelerate a vehicle from geosynchronous orbit (GEO) to low-earth orbit (LEO). After being deployed from the Space Shuttle in LEO, the AFE will accelerate (using a small solid rocket motor) to speeds matching a return trajectory to Earth from GEO. Upon entering the Earth's atmosphere, with a low flight path angle, the vehicle will effectively "skim" the atmosphere dissipating kinetic energy in the form of drag on the vehicle. By controlling the amount of time spent in the atmosphere, the energy lost can be regulated, thus allowing the desired orbital apogee to be attained. After reaching the desired apogee (200 n.mi.), the AFE will circularize its orbit and the Shuttle will retrieve it.

The AFE will fly through a region of the atmosphere known as the transition region. This region is located between the layers of the atmosphere which can be modeled by free molecular flow theory and those modeled by continuum flow theory. One of the objectives of this experiment is to determine which theoretical representation of that transition region is most accurate. Since there are several transition theories at the present time, the guidance of the AFE will be expected to successfully complete its mission no matter which theory is used. The four transition theories used to calculate various atmospheric data in the Program to Optimize Simulated Trajectories (POST) are the Viking Transition Equations, the Lockheed Bridging Formula, the Potter Method, and the Shock Reynolds Number Method [1]. POST also includes a variation of the Shock Reynolds Number Method which corrects for the drag only and assumes a constant lift coefficient.

For this paper the AFE's trajectory was simulated by POST. The basic configuration of the AFE input into POST for these tests (see fig. 1) weighs 2741 pounds, has an aerodynamic reference area of 154 square feet and an aerodynamic reference length of 14 feet. The guidance algorithm which has been proposed for the AFE [2] was implemented into POST. This guidance adjusted the bank angle to maintain a constant altitude rate during entry until a specified velocity had been reached (the entry phase), at which point the exit phase of the aerobraking pass began. During the exit phase, the guidance utilizes an analytic predictor/corrector to attain the desired apogee altitude for rendezvous with the Shuttle.

This paper addresses two main issues concerning this guidance. First, an investigation of certain gains was made concentrating on their values and the effect these values had on the bank angle commanded by the guidance. Second, adaptations to the guidance were studied to allow various experiments on the AFE to be conducted with little or no contamination from the Reaction Control System (RCS).

APPROACH

For the simulation of the AFE trajectory and the determination of an adequate solution, certain specific criteria were used and monitored. The initial conditions for the AFE trajectory were given as: 400,000 feet altitude; 28.5 degree-angle of inclination; an inertial velocity of 33,828.6 feet/second; flight path angle of -4.5 degrees; and an angle of attack of 17 degrees. A successful run consisted of: (a) a maximum heat rate less than 150 Btu/ft^2-sec +/-5 Btu/ft^2-sec; (b) an inclination angle of 28.5 degrees +/- .1 degrees; (c) an apogee altitude of 200 n.mi. +/- 20 n.mi.; (d) a tendency of the lift vector toward the down position (0 degree bank angle) at exit; and (e) less than 5 bank reversals before exiting the atmosphere. A run was considered acceptable if it met the above criteria except: (c) an apogee altitude of 200 n.mi. +/- 25 n.mi. Otherwise, if none of the above criteria was met, the run was considered unsuccessful. The tendency of the lift vector towards the down position reflects that the flight path angle is small which is desired for rendezvous with the Shuttle [2]. The smaller the flight path angle is, the less change in velocity is required for circularization to maneuver into a shuttle rendezvous orbit. A lift vector up (180 degree bank angle) is not desired as the perigee altitude is not raised (as is the case for the lift vector down) and more change in velocity is needed for circularization. The number of roll reversals of the bank angle reflects the amount of RCS fuel required to maintain the desired orbital plane (the fewer the reversals, the less the amount of fuel used).

Some gains in the AFE guidance were varied to find a set which met prearranged exit criteria and commanded a minimum number of roll reversals in the bank angle. The gains examined for this purpose were GHDOT during the entry phase, GHDOT during the exit phase, and K1. GHDOT is the gain associated with an attitude damping factor to negate rapid altitude changes, (eqn.(5) in [2]). K1 is associated with the amount of density variation from the 1962 Standard Atmosphere taken into account [2]. The various gains were tested on POST for the 1976 Standard Atmosphere with no transition equations implemented as an initial run. Next the most promising sets of gains were tested on the 1962 Standard Atmosphere with no transition equations. Finally, the best set of gains for both runs was tested on the two atmospheres with the transition equations included.

During entry into the atmosphere, the AFE will be conducting sensitive scientific experiments [3]. In a certain region (referred to as the clean or coast region), the experiments will be especially active and sensitive. This region lies between a point known as the science "point" (approximately 85 km from the Earth's surface) and perigee (in this paper perigee is defined as the lowest altitude at which the flight path angle is zero). Since the Reaction Control System (RCS) releases gases close to the vehicle (and the experiments) when performing bank angle changes, a "quiet" (no maneuvering) period in the guidance is requested during the coast region to reduce the possibility of contaminating the area around the experiments. In order to insure that no maneuvering occurs in this region, slight modifications were made to the guidance algorithm and the AFE's trajectory. Three methods were studied to obtain the "quiet" period (at least 20, preferably 30 seconds long) during the coast region. These methods were: the two (2) degree out-of-plane hold; the "plateau" hold; and the "add-out/take-in" method.

The two (2) degree out-of-plane hold consists of starting the AFE two (2) degrees out of the desired orbital inclination plane (at 26.5 and not 28.5 degrees) and holding the bank angle at some value so that the aerodynamic forces will bring the vehicle back into plane. Then the guidance is cut on at perigee. For this paper, a bank angle of 97.6 degrees was chosen from a POST optimization run which started two degrees out of plane, used no guidance or controlling mechanism, and met all exit criteria (except the inclination angle). The two degree out-of-plane hold was suggested as a viable method because of its relative simplicity, thus its easy implementation.

The "plateau" hold begins the trajectory with the guidance turned on (being accessed) until a natural "plateau" in the bank angle profile occurs. The "plateau" (see fig. 2) is the natural "leveling off" or the nearing of a constant value of the bank angle to some quantity (approximately 100 degrees) just prior to the coast region. At this "plateau", two different methods were used. First, at an inertial velocity of 32,500 feet/second the bank angle is increased to 106.88 degrees and held through the coast region. Second, the guidance is cut off through the coast region when the bank angle reaches 106.88 degrees. The velocity value chosen in method (1) occurs during the aforementioned "leveling off" section of the bank profile. The choice of 106.88 degrees for the bank angle was purely arbitrary, but it was retained after some success using it in initial runs. The "plateau" hold attempts to delay the first roll reversal of the bank angle profile until after the coast region, minimizing the RCS firings during that time. This method was also relatively easy to implement.

The "add-out/take-in" method involved increasing the commanded bank angle a certain amount at a predetermined velocity for a brief period (add-out). Then, the increased angle was decreased a small amount just prior to the coast region (take-in). Finally, the latest bank angle value was held during the coast region. The angle was held in the coast region initially for 20 seconds, then 25 and 30 seconds, if the initial run was acceptable. The velocity used for the add-out trigger was 33,000 feet/second. This value for the velocity was chosen since it occurs at approximately 25 to 30 seconds before perigee (for the nominal atmosphere case). This method also attempts to delay the first roll reversal of the bank angle by reducing the amount of out of plane velocity, thus, causing the guidance to "think" the AFE does not require a roll reversal until a later time. This method was not as easy to implement as the other two, but must, on average, have a bank angle for the "quiet time" that enables the AFE to reach the desired apogee altitude.

RESULTS AND DISCUSSION

The first task in this investigation was to establish a set of gains that would give acceptable results for the 1962 and 1976 atmospheres and all transition equations. The gains varied were: GHDOT(entry), GHDOT(exit), and K1. GHDOT(entry) was set to .18,.20,or .25. GHDOT(exit) was set to .15, .20, or .25. K1 was set to .10,.15, or .20. Various combinations of these gains were tested for the two atmospheres and five transitions. The gain sets with GHDOT(entry)=.2, GHDOT(exit)=.25, and any of the three values for K1 gave the smoothest bank angle time histories and the apogee altitudes closest to 200 nautical miles. Since other investigators had used K1=.2 [2] this value was used for the "quiet time" studies. The results of using the gain set described above are given in Table I and the bank angle time histories are shown as figures 2 and 3. As observed in [1] the atmosphere assumed had a significant effect on the bank angle required to keep the vehicle in plane and meet the apogee altitude requirement. Also, the transitions using the Potter number and the Shock Reynolds number changed the bank angle profiles required to meet the mission objectives.

Next, the runs of the various methods to provide a "quiet" period in the guidance were examined. The success criteria were reduced to meeting the heating, orbital inclination, and apogee constraints listed above. The two (2) degree out-of-plane hold results were not acceptable. The AFE never exited the Earth's atmosphere; it lost too much energy trying to correct for the out-of-plane velocities during the initial part of the exit phase. The corrective maneuvers caused the AFE to spend too much time in the higher density region of the atmosphere resulting in the excessive loss of energy. This was the only attempt using this method that was made, and other implementations of this technique could possibly give better results than the ones recorded here.

The first method in the "plateau" hold gave acceptable results for both the nominal atmospheres (no transition equations used) and all of the transition runs when held for 20 seconds (see figures 4 and 5 and Table II). Bank angle is designated as ϕ in Tables II through VIII. When the "plateau" hold was used for 30 seconds the starting velocity was changed to 33,000 ft/sec so that the guidance would cut on before perigee. Even with this change the runs using the 1962 atmosphere went past perigee before the guidance was cut on (see figure 6). The passing of perigee is indicated when the dashed curve (flight path angle GAMMAI on the figures) crosses zero. The results of the 30-second "quiet time" runs were acceptable for the 1976 standard atmosphere and all transitions except the Potter transition. The results were acceptable for the 1962 standard atmosphere and all transitions (see Table III and figures 6 and 7). The second "plateau" method was run for both nominal atmospheres and the Lockheed and Shock Reynolds number transitions. In these runs the "quiet time" was held for 30 seconds with both nominal atmosphere cases and all of the transition runs giving successful results except for the Shock Reynolds Number for the 1976 atmosphere (see Table IV and figures 8 and 9). As was the case for the first "plateau" method, the runs using the 1976 atmosphere cut the guidance back on before perigee, but the runs using the 1962 atmosphere did not (figure 8(a)). Since the runs that went past perigee still had acceptable apogee altitudes, the effect of keeping the guidance off past perigee is not clear. Because the guidance changes modes after perigee cutting it back on by perigee seemed advisable; however, the true impact can only be assessed when cases with errors are examined. The first variation of the "plateau" hold was used to show the sensitivity of the performance of the guidance to the choice of the bank angle. When the bank angle was increased two (2) degrees from the 106.88 degrees used, the originally acceptable 1976 atmosphere nominal run was no longer acceptable (the apogee altitude fell from 194.5 n.mi. to 153.7 n.mi.). However, when the bank angle was increased 1.5 degrees the results were acceptable (an apogee altitude of 186.0). This shows that a two (2) degree error in the bank angle at this critical time in the guidance could cause the trajectory to become unacceptable. There is, however, about a degree and a half of tolerance. In all cases the inclination angle variation from nominal was less than .05 degrees and although not shown in tables the nodal variation was less than .15 degrees. This nodal error could add up to 30 ft/sec to the ΔV required for circularization in a proper orbit for rendezvous.

A number of bank angle combinations were tried during the out-in technique study. A typical bank profile is shown as figure 10(a). The final bank angle that was to be held for 20 to 30 seconds was critical. If the bank angle held varied more than 5 degrees from the "plateau" value then the results using the 1962 atmosphere were adversely affected. Bank angles of 5 degrees or greater from the "plateau" value in many cases gave improved results when a 1976 atmosphere was used. The cases shown in this paper to illustrate the technique all returned to the "plateau" bank angle. These runs were chosen because they went through a normal guidance sequence while in the atmosphere for both atmospheres and all transitions. While the apogee altitude was not acceptable for most of the 1976 atmosphere runs, these runs were not terminated early because they had violated a criterion of the simulation.

The results of the 25 degrees out-in runs with a 20-second "quiet time" are shown as Table V and figures 10 and 11. The results were acceptable for all the runs using the 1962 atmosphere, but for only one run using the 1976 atmosphere. When the "quiet time" was extended to 30 seconds all the 1962 atmosphere runs were still acceptable, but the apogee altitude attained degraded and the number of roll reversals became large. Only one of the 1976 atmosphere runs had an acceptable apogee altitude, but the apogee altitudes of all runs were closer to the desired altitude (Table VI and figures 12 and 13).

The results of the 35 degree out-in runs are shown as Tables VII and VIII, and figures 14 through 17. The 20-second "quiet time" runs were acceptable for both atmospheres and all transitions, but the number of roll reversals again was large for the 1962 atmosphere runs. When the "quiet time" was extended to 30 seconds none of the 1976 atmosphere runs had acceptable apogee altitudes, but two of the runs were close. All of the 1962 atmosphere runs had acceptable apogee altitudes and the run using the Shock Reynolds number had only two roll reversals.

An examination of the runs shown indicates that a combination of out-in angles could be found that would give acceptable results for all cases under ideal conditions. However, in the presence of potential dispersions any combination of out-in angles could have trouble meeting the apogee requirement. Another possible problem is the amount of maneuvering required just before the "quiet time". Since the purpose in cutting the guidance off is to have as little RCS contamination as possible during the time of maximum scientific interest, a minimum of maneuvering before the "quiet time" seems desirable.

As before many of the runs did not cut the guidance on until after perigee. Figures 14 through 17 show that the guidance was off for all cases when the 35 degree out-in modification to the guidance was used. When the 25 degree out-in modification was used the guidance was cut back on before perigee for the 1976 atmosphere runs, but not for the 1962 atmosphere runs. Since all the 1962 atmosphere runs had acceptable apogee altitudes for the ideal case leaving the guidance off past perigee could be acceptable, but at present this does not seem desirable. As with the plateau runs, the inclination angle error was less than .05 degrees and the nodal error less than .15 degrees.

CONCLUDING REMARKS

A set of gains that gave reasonable guidance performance for the 1962 and 1976 standard atmospheres and five transition models was established. The guidance with these gains was used to investigate modifications to the AFE guidance to establish a "quiet time" just before perigee of the aeropass trajectory. The modifications were investigated for ideal conditions and no errors or atmospheric dispersions were introduced. Several of the methods gave acceptable results for a 20-second "quiet time". When this time was extended to 30 seconds, runs using some of the transition models with the 1976 atmosphere did not meet the apogee altitude targets. The runs using the 1962 atmosphere did not cut the guidance back on until after perigee in all cases, but all cases meet the criteria for successful runs. The general conclusion from the studies was that a 30-second "quiet time" was possible, but the effect of leaving the guidance off for that long must be better assessed to assure the safety of the mission.

The studies raised a number of questions and pointed toward several investigations that are required to determine the modifications that can be safely made to the AFE guidance to give a "quiet time" of 30 seconds. The questions that need to be answered are:

1. What is the effect of leaving the guidance off past perigee?

2. What quantity or quantities should be monitored to determine if turning the guidance off is endangering the mission?

3. The methods examined assume a fixed bank angle for 20 or 30 seconds. In the actual case there will be some drift in the bank angle. How much can the bank angle change and have the vehicle exit to an acceptable apogee?

4. Will the "quiet time" requirement for the AFE mission dictate a different guidance scheme?

5. Can gains be determined so that the guidance will be less sensitive to the atmosphere encountered?

To better assess the impact of a 30-second "quiet time" additional studies must be conducted. A partial list is:

1. Conduct studies that include system errors and atmospheric dispersions to see if leaving the guidance off past perigee is practical.

2. If the guidance must be cut on at or before perigee, determine the best way to modify the existing guidance to get a 30-second "quiet time" before perigee using a minimum of maneuvers.

3. If modification of the existing guidance becomes too involved, consider other guidance schemes such as an adaptive system or a predictor-corrector method for the entry phase of the braking maneuver.

4. A fixed set of gains is desired for the AFE guidance. The gains used in this study are for the "nominal" case, not the "quiet time" case. When a "quiet time" method has been determined a set of gains that result in fewer roll reversals must be designed.

REFERENCES

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TABLE I.- RUNS WITH GUIDANCE

Transition model	Inclination angle	Apogee altitude	Max heat rate	ΔV to circularize	Atmosphere
None	28.43 deg	199.65 nm'	151.9 $\frac{Btu}{ft^2\text{-sec}}$	300.4 ft/sec	1962
Viking	28.41 deg	196.7 nm	151.8 $\frac{Btu}{ft^2\text{-sec}}$	269.9 ft/sec	1962
Lockheed	28.42 deg	197.7 nm	151.8 $\frac{Btu}{ft^2\text{-sec}}$	298.5 ft/sec	1962
Potter	28.47 deg	195.2 nm	149.9 $\frac{Btu}{ft^2\text{-sec}}$	297.5 ft/sec	1962
Shock Reynolds Number	28.46 deg	192.8 nm	150.4 $\frac{Btu}{ft^2\text{-sec}}$	264.4 ft/sec	1962
None	28.43 deg	197.3 nm	149.6 $\frac{Btu}{ft^2\text{-sec}}$	313.5 ft/sec	1976
Viking	28.48 deg	196.2 nm	149.5 $\frac{Btu}{ft^2\text{-sec}}$	322.1 ft/sec	1976
Lockheed	28.46 deg	195.7 nm	149.6 $\frac{Btu}{ft^2\text{-sec}}$	315.9 ft/sec	1976
Potter	28.45 deg	192.8 nm	147.1 $\frac{Btu}{ft^2\text{-sec}}$	325.9 ft/sec	1976
Shock Reynolds Number	28.48 deg	195.1 nm	147.6 $\frac{Btu}{ft^2\text{-sec}}$	318.0 ft/sec	1976

TABLE II.- BANK ANGLE HOLD FOR 20-SECOND "QUIET TIME"

Run description	Inclination angle	Apogee altitude	Max heat rate	ΔV to circularize	Reversals	Atmosphere and transition	Lift tendency at exit
Cut @ V = 32,500 ft/sec Hold ϕ = 106.88°	28.53	197.4 ft	151.8 $\frac{Btu}{ft^2\text{-sec}}$	303.2 ft/sec	10	1962 None	Up
↓	28.52	195.4 ft	151.7 $\frac{Btu}{ft^2\text{-sec}}$	293.8 ft/sec	8	1962 Viking	Down
↓	28.53	196.2 ft	151.7 $\frac{Btu}{ft^2\text{-sec}}$	295.7 ft/sec	8	1962 Lockheed	Down
↓	28.53	194.8 ft	149.9 $\frac{Btu}{ft^2\text{-sec}}$	300.3 ft/sec	9	1962 Potter	Up
↓	28.54	190.2 ft	150.4 $\frac{Btu}{ft^2\text{-sec}}$	294.6 ft/sec	10	1962 Shock Reynolds	Up
Cut @ V = 32,500 ft/sec Hold ϕ = 106.88°	28.54	183.6 ft	148.8 $\frac{Btu}{ft^2\text{-sec}}$	295.6 ft/sec	7	1976 None	Neutral
↓	28.53	183.0 ft	148.7 $\frac{Btu}{ft^2\text{-sec}}$	301.2 ft/sec	7	1976 Viking	Down
↓	28.53	184.3 ft	148.8 $\frac{Btu}{ft^2\text{-sec}}$	304.5 ft/sec	7	1976 Lockeed	Down
↓	28.53	184.4 ft	146.7 $\frac{Btu}{ft^2\text{-sec}}$	304.6 ft/sec	6	1976 Potter	Up
↓	28.54	180.0 ft	147.3 $\frac{Btu}{ft^2\text{-sec}}$	298.2 ft/sec	6	1976 Shock Reynolds	Up

TABLE III.- BANK ANGLE HOLD FOR 30-SECOND "QUIET TIME"

Run description	Inclination Angle	Apogee altitude	Max heat rate	ΔV to circularize	Reversals	Atmosphere and transition	Life Tendency at exit
Cut @ V = 33,000 ft/sec Hold ϕ = 106.88°	28.52°	198.5 ft	151.7 $\frac{Btu}{ft^2\text{-sec}}$	298 ft/sec	8	1962 None	Down
↓	28.53°	194.5 ft	151.6 $\frac{Btu}{ft^2\text{-sec}}$	295 ft/sec	10	1962 Viking	Down
↓	28.52°	196.7 ft	151.6 $\frac{Btu}{ft^2\text{-sec}}$	295.7 ft/sec	8	1962 Lockheed	Down
↓	28.52°	194.8 ft	150.0 $\frac{Btu}{ft^2\text{-sec}}$	295.3 ft/sec	8	1962 Potter	Down
↓	28.52°	186.4 ft	150.2 $\frac{Btu}{ft^2\text{-sec}}$	288 ft/sec	10	1962 Shock Reynolds	Up
Cut @ V = 33,000 ft/sec Hold ϕ = 106.88°	28.54°	181.2 ft	148.1 $\frac{Btu}{ft^2\text{-sec}}$	290 ft/sec	8	1976 None	Up
↓	28.53°	175.2 ft	148.0 $\frac{Btu}{ft^2\text{-sec}}$	282.2 ft/sec	8	1976 Viking	Up
↓	28.52°	180.3 ft	148.0 $\frac{Btu}{ft^2\text{-sec}}$	290.4 ft/sec	8	1976 Lockheed	Up
↓	28.52°	173.6 ft	146.1 $\frac{Btu}{ft^2\text{-sec}}$	279 ft/sec	8	1976 Potter	Down
↓	28.52°	176.5 ft	146.7 $\frac{Btu}{ft^2\text{-sec}}$	291 ft/sec	6	1976 Shock Reynolds	Up

TABLE IV.- 30-SECOND "QUIET TIME"

Run description	Inclination angle	Apogee altitude	Max heat rate	ΔV to circularize	Reversals	Atmosphere and transition	Lift Tendency at exit
Hold ϕ at 106.88° ↓	28.53°	197.4 nm	151.6 $\frac{Btu}{ft^2\text{-sec}}$	300.8 ft/sec	10	1962 None	Down
	28.50°	195.9 nm	151.6 $\frac{Btu}{ft^2\text{-sec}}$	311.7 ft/sec	11	1962 Lockheed	Up
	28.54°	192.1 nm	150.3 $\frac{Btu}{ft^2\text{-sec}}$	290.5 ft/sec	10	1962 Shock Reynolds	Down
Hold ϕ at 106.88° ↓	28.50°	191.6 nm	147.0 $\frac{Btu}{ft^2\text{-sec}}$	303.9 ft/sec	7	1976 None	Down
	28.51°	184.7 nm	146.7 $\frac{Btu}{ft^2\text{-sec}}$	295.2 ft/sec	7	1976 Lockheed	Up
	28.52°	171.0 nm	146.0 $\frac{Btu}{ft^2\text{-sec}}$	287.5 ft/sec	6	1976 Shock Reynolds	Up

TABLE V.- 25 DEGREE OUT-IN GUIDANCE MODIFICATION WITH 20-SECOND "QUIET TIME"

Run description	Inclination angle, deg	Apogee altitude, nm	Maximum heat rate, Btu/ft^2 sec	ΔV to circularize ft/sec	Reversals	Atmosphere and transition	Lift tendency at exit
25° out and 25° in Hold ϕ for 20 sec	28.50	180.0	147.5	287.2	8	1976 None	Down
↓	28.49	145.3	147.8	247.5	7	1976 Lockheed	Down
↓	28.48	143.0	145.9	246.1	8	1976 Shock Reynolds	Down
25° out and 25° in Hold ϕ for 20 sec	28.53	196.8	150.3	294.7	12	1962 None	Up
↓	28.48	195.9	150.0	295.3	6	1976 Lockheed	Up
↓	28.46	191.6	148.7	295.8	9	1962 Shock Reynolds	Up

TABLE VI.- 25 DEGREE OUT-IN GUIDANCE MODIFICATION WITH 30-SECOND "QUIET TIME"

Run description	Inclination angle, deg	Apogee altitude, nm	Maximum heat rate, Btu/ft^2 sec	ΔV to circularize ft/sec	Reversals	Atmosphere and transition	Lift tendency at exit
25° out and 25° in Hold ϕ for 30 sec	28.55	184.2	147.8	282.3	6	1976 None	Down
↓	28.53	155.8	147.8	265.2	8	1976 Lockheed	Up
↓	28.52	162.6	146.0	277.6	8	1976 Shock Reynolds	Up
25° out and 25° in Hold ϕ for 30 sec	28.5	176.3	150.1	291.4	24	1962 None	Up
↓	28.5	191.3	150.0	287.3	15	1962 Lockheed	Up
↓	28.5	191.5	148.7	288.2	16	1962 Shock Reynolds	Down

TABLE VII.- 35 DEGREE OUT-IN GUIDANCE MODIFICATION WITH 20-SECOND "QUIET TIME"

Run description	Inclination angle, deg	Apogee altitude, nm	Maximum heat rate, Btu/ft^2 sec	ΔV to circularize ft/sec	Reversals	Atmosphere and transition	Lift tendency at exit
35° out and 35° in Hold ϕ for 20 sec	28.53	180.0	147.0	285.0	6	1976 None	Up
↓	28.49	177.8	146.6	298.1	6	1976 Lockheed	Up
↓	28.52	182.7	145.5	299.7	6	1976 Shock Reynolds	Up
35° out and 35° in Hold ϕ for 20 sec	28.54	199.9	149.9	290.0	12	1962 None	Down
↓	28.54	195.11	150.0	286.4	14	1962 Lockheed	Down
↓	28.54	183.5	148.6	269.4	18	1962 Shock Reynolds	Down

TABLE VIII.- 35 DEGREE OUT-IN GUIDANCE MODIFICATION WITH 30-SECOND "QUIET TIME"

Run description	Inclination angle, deg	Apogee altitude, nm	Maximum heat rate, Btu/ft^2 sec	ΔV to circularize ft/sec	Reversals	Atmosphere and transition	Lift tendency at exit
35° out and 35° in Hold ϕ for 30 sec	28.54	146.3	146.7	268.3	12	1976 None	Up
↓	28.54	172.7	146.6	274.6	8	1976 Lockheed	Up
↓	28.54	168.7	145.0	271.4	8	1976 Shock Reynolds	Up
35° out and 35° in Hold ϕ for 30 sec	28.57	203.6	149.2	285.3	22	1962 None	Down
↓	28.56	206.0	149.2	291.6	14	1962 Lockheed	Down
↓	28.56	220.4	147.9	314.6	2	1962 Shock Reynolds	Down

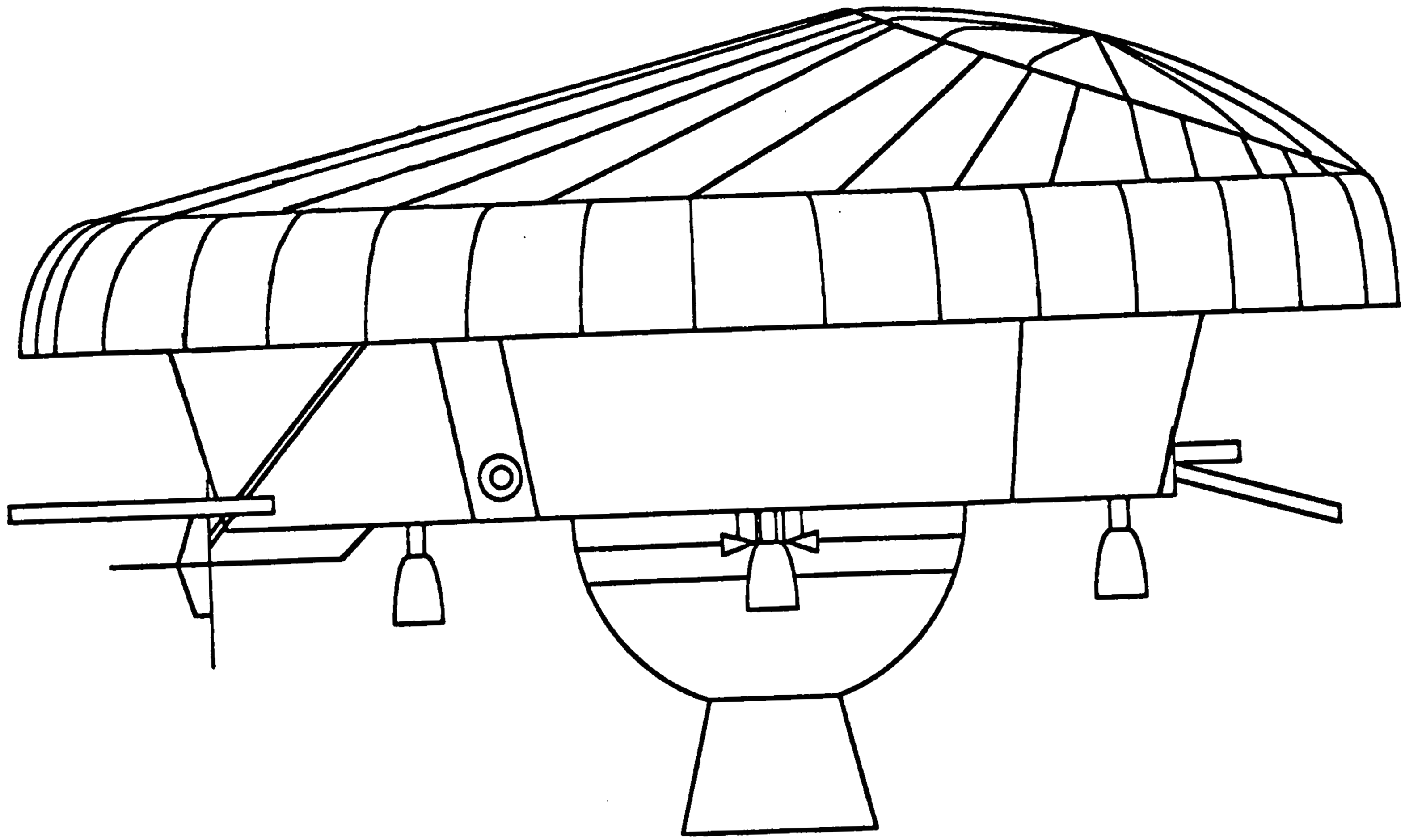
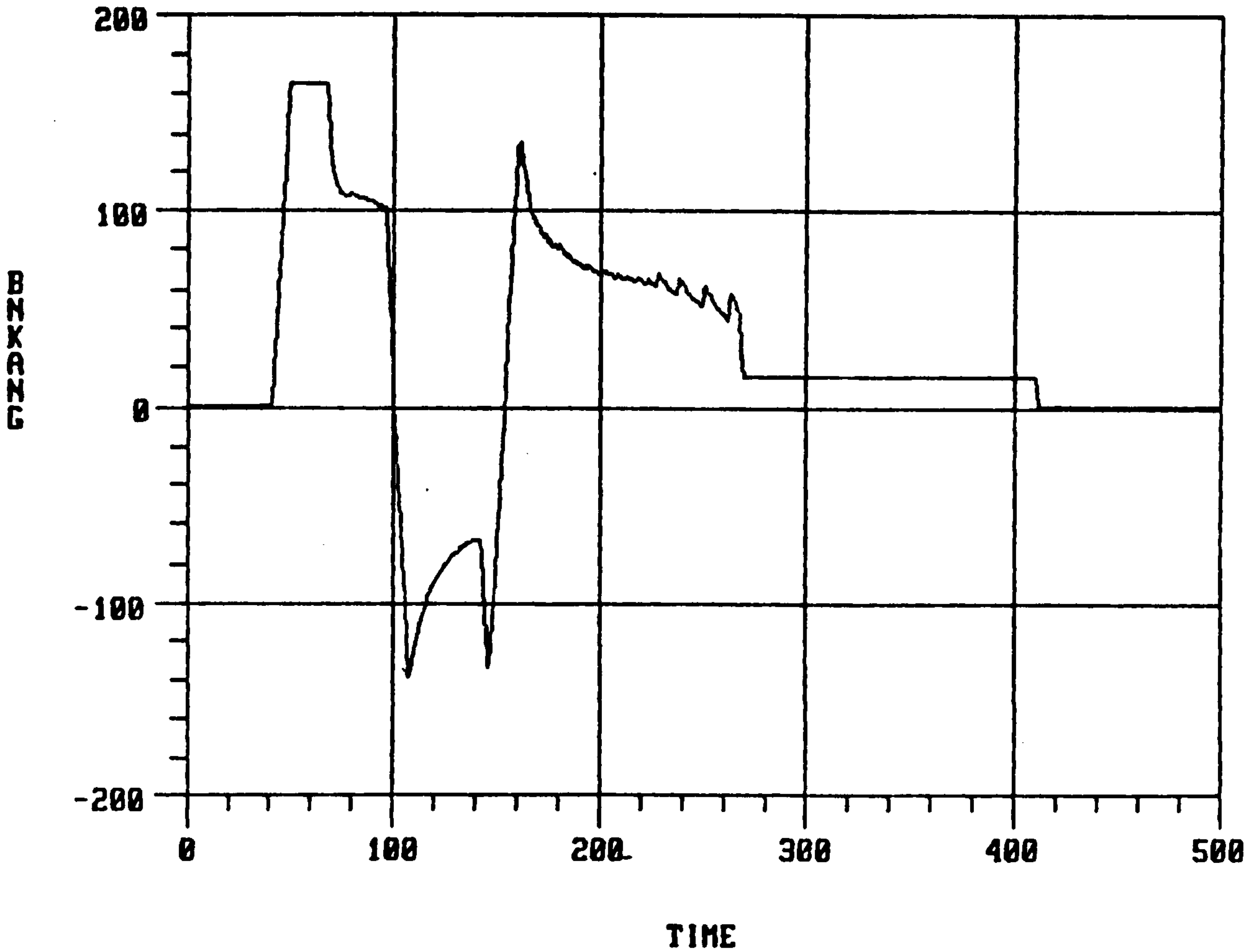
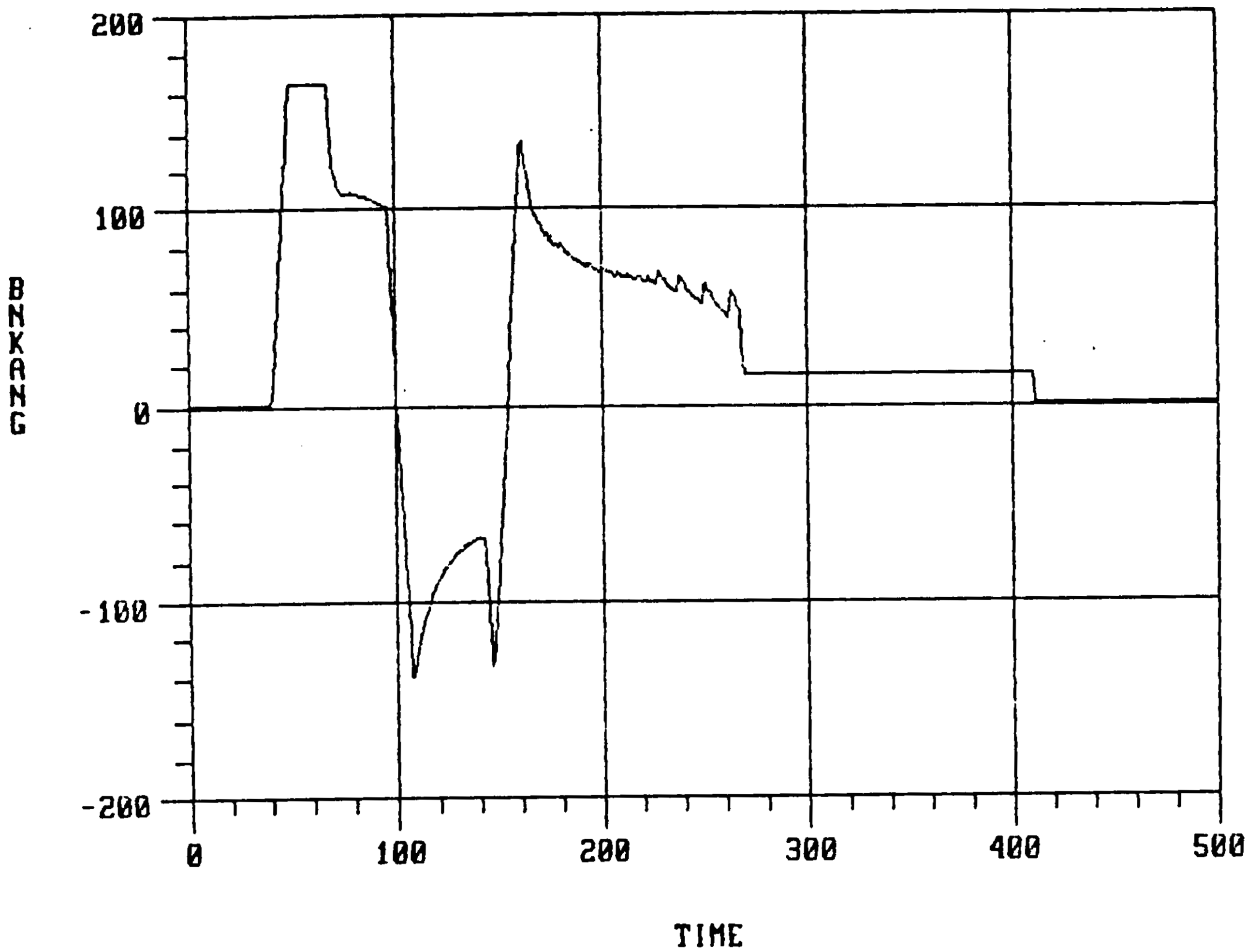


Figure 1. AFE test vehicle.



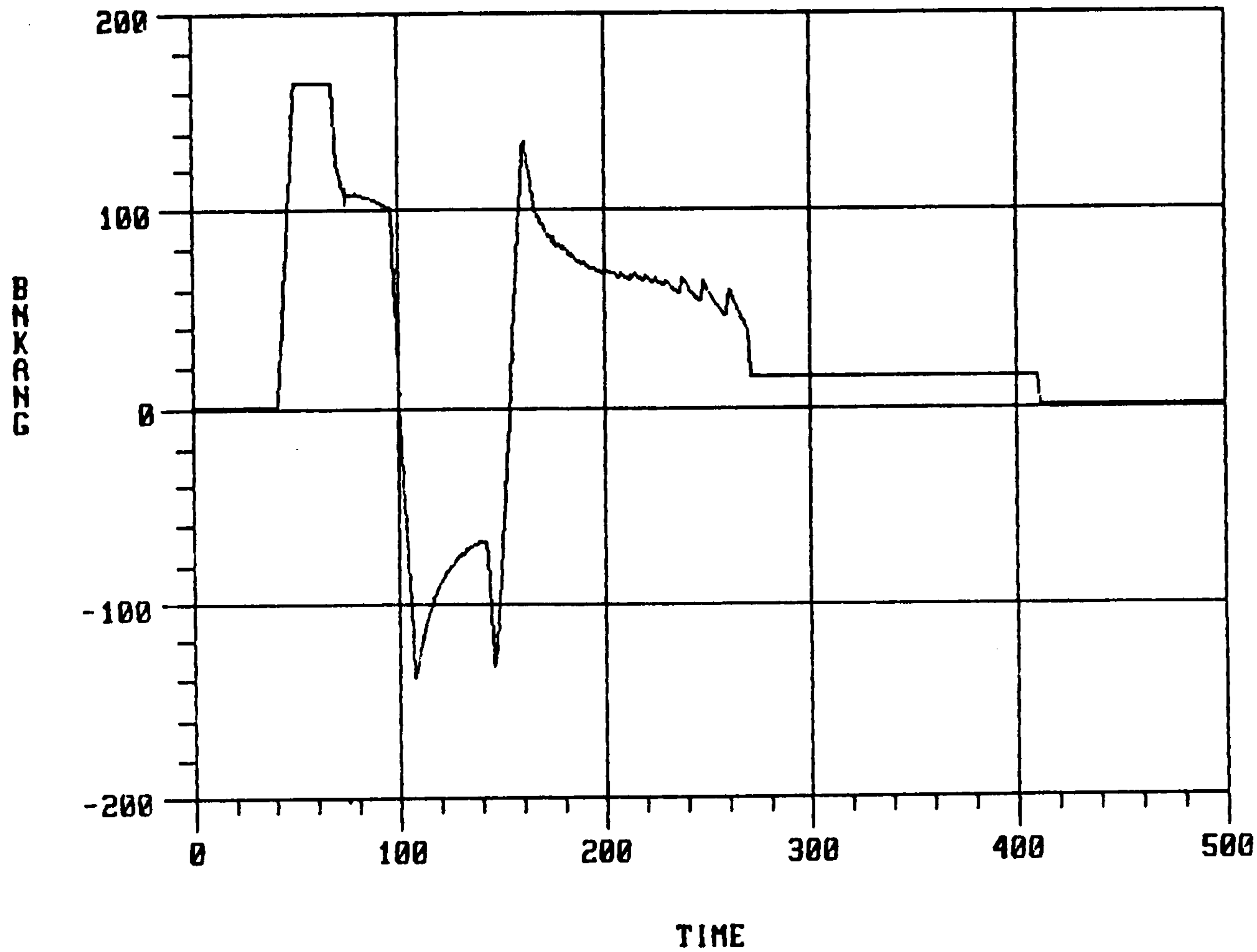
(a) No transition.

Figure 2. Bank angle time history for runs with 1962 atmosphere.



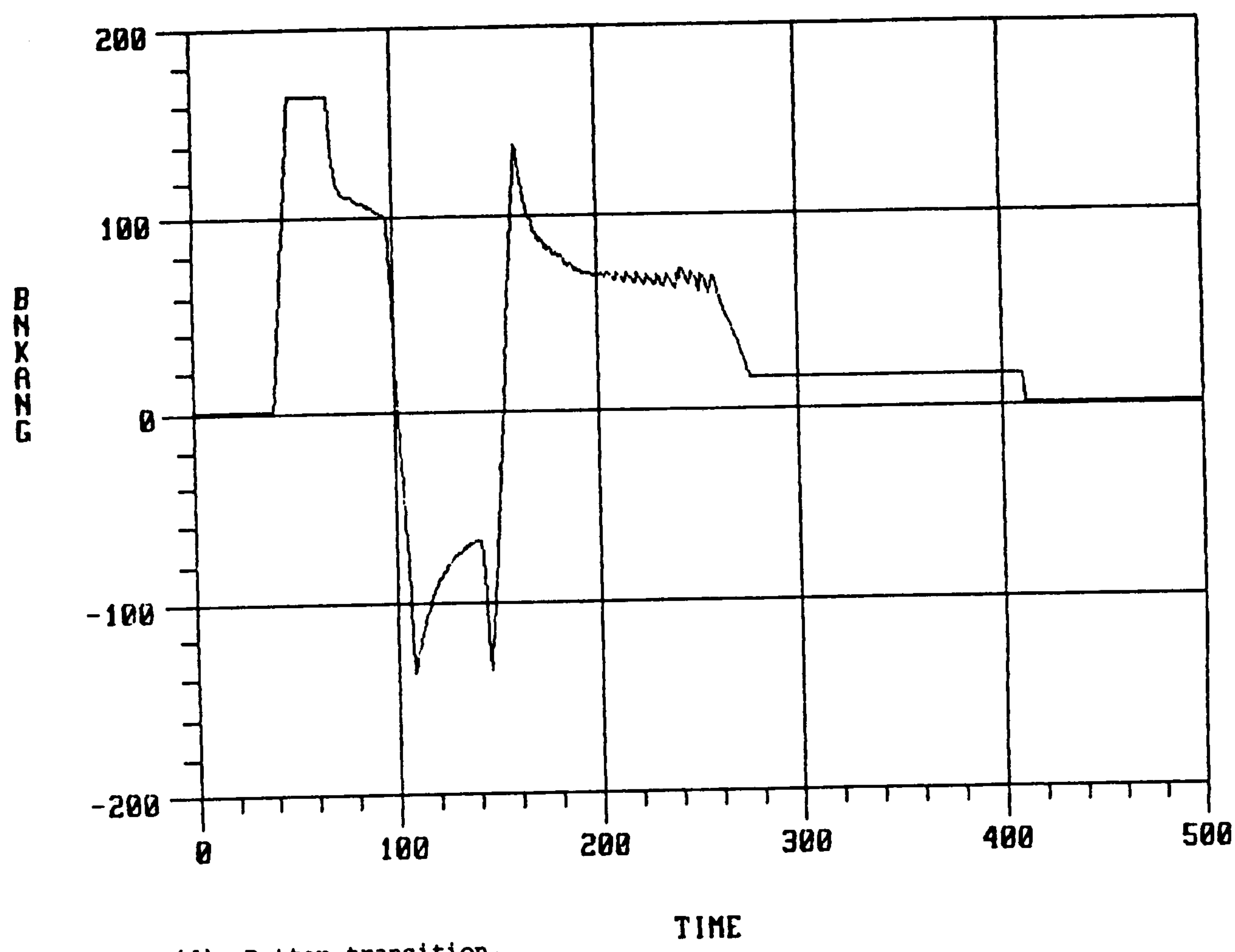
(b) Viking transition.

Figure 2. Continued.



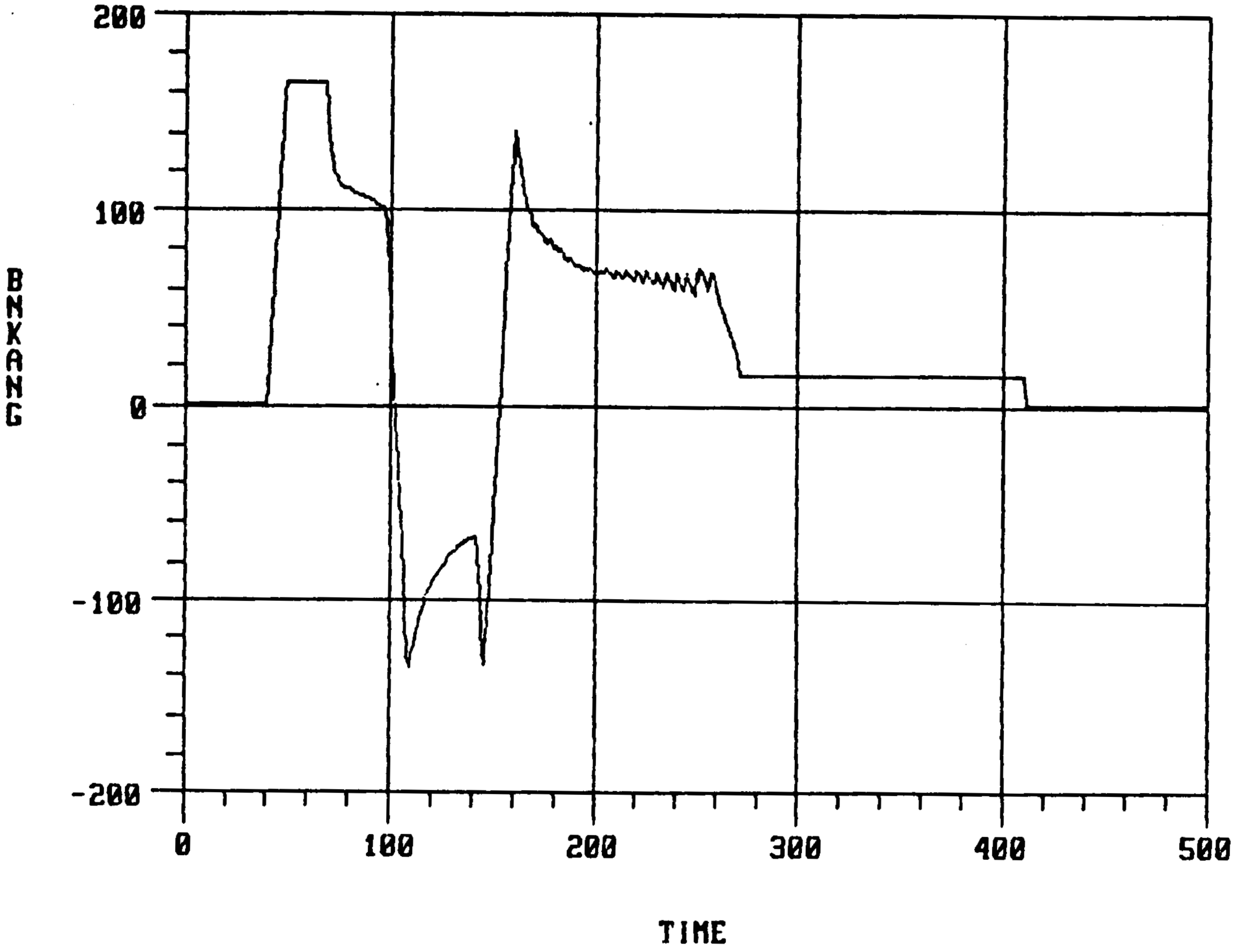
(c) Lockheed transition.

Figure 2. Continued.



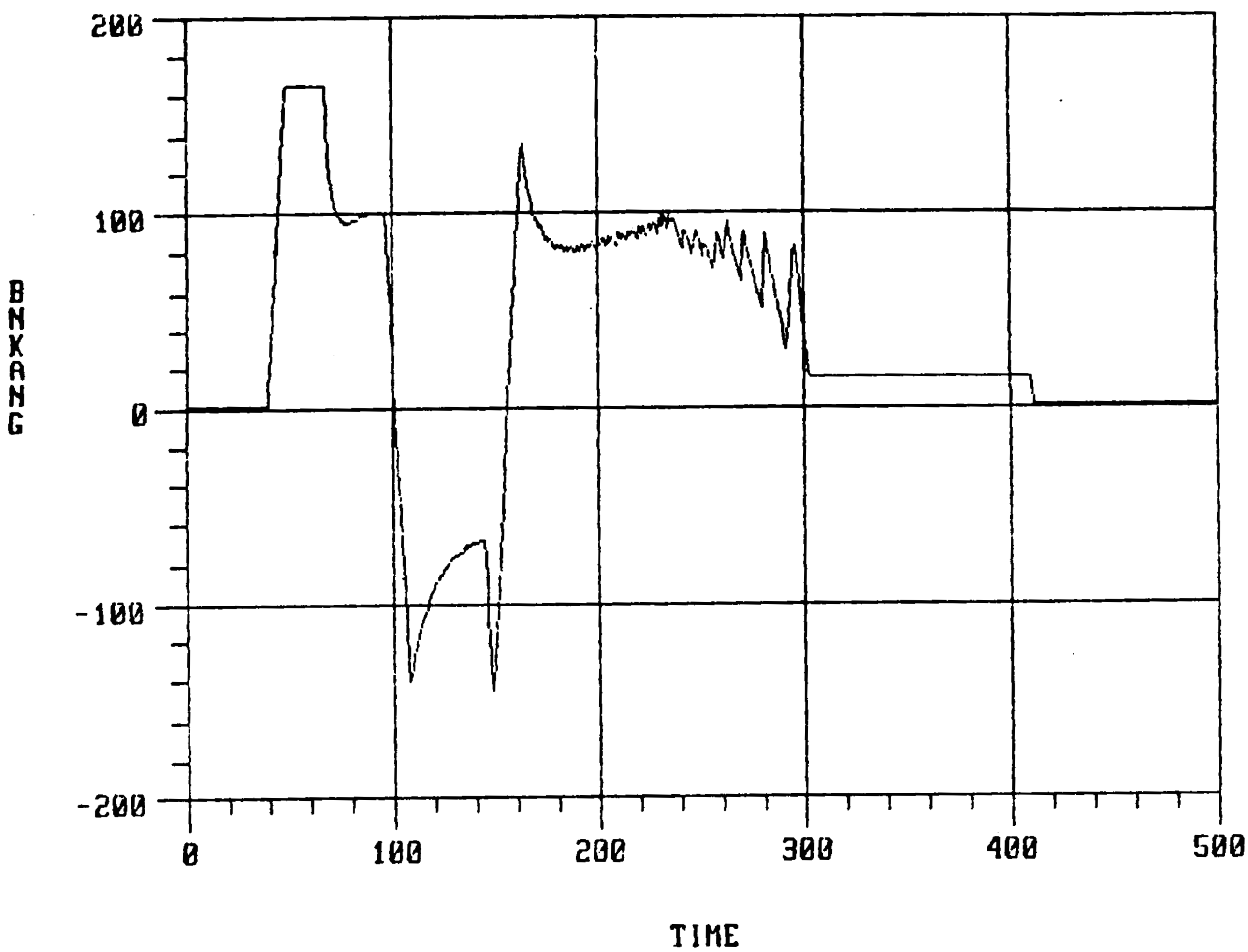
(d) Potter transition.

Figure 2. Continued.



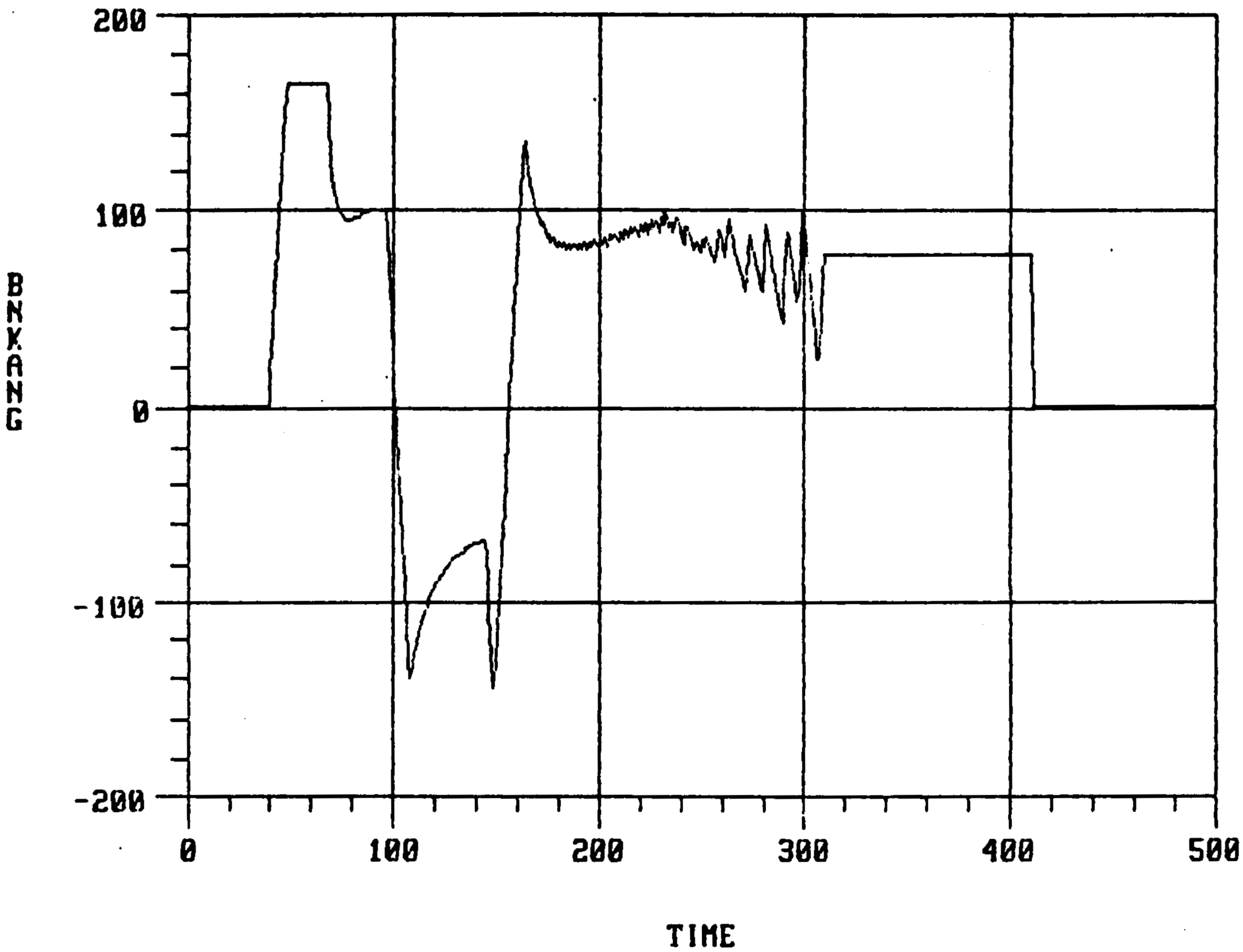
(e) Shock Reynolds number transition.

Figure 2. Concluded.



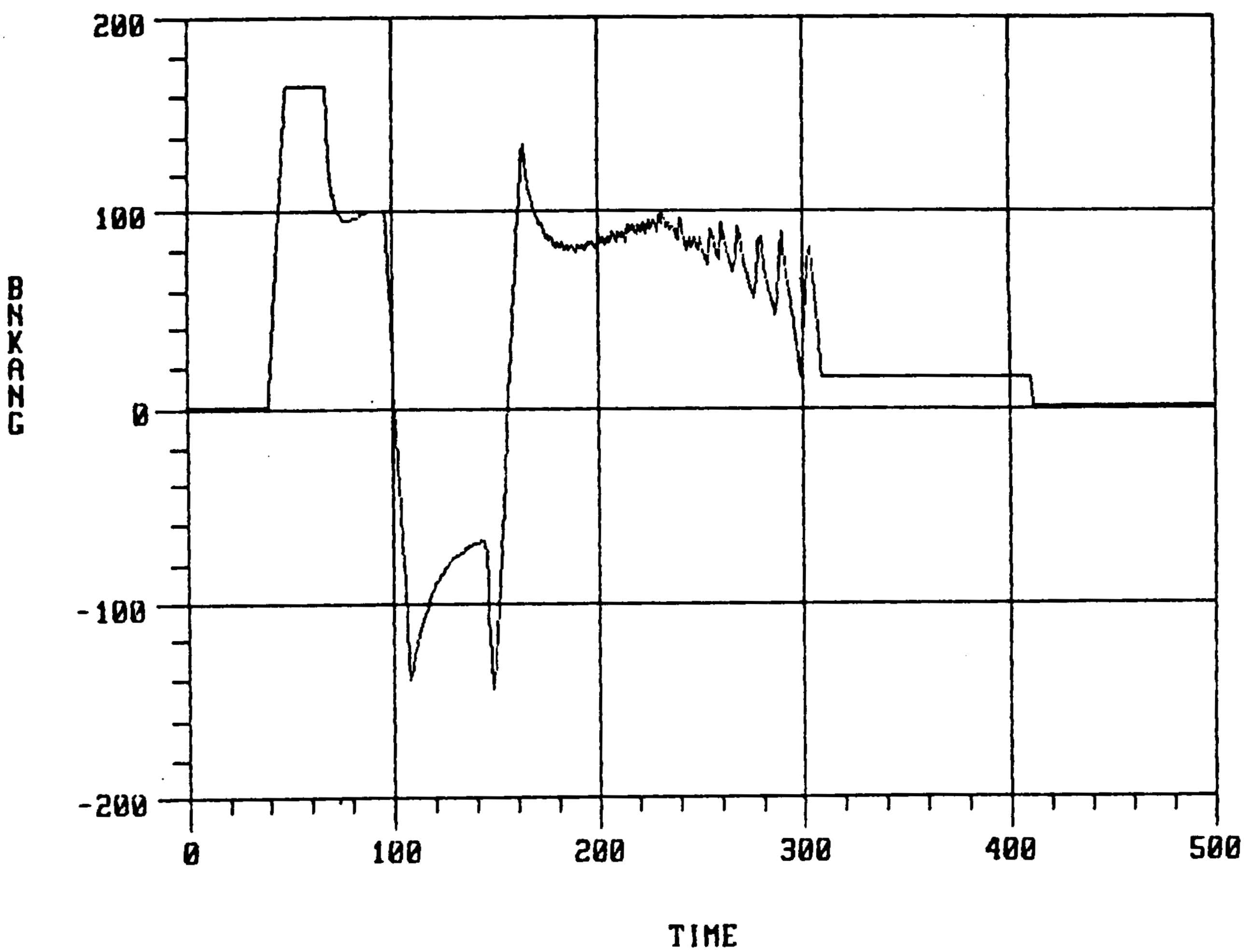
(a) No transition.

Figure 3. Bank angle time history for runs with 1976 atmosphere.



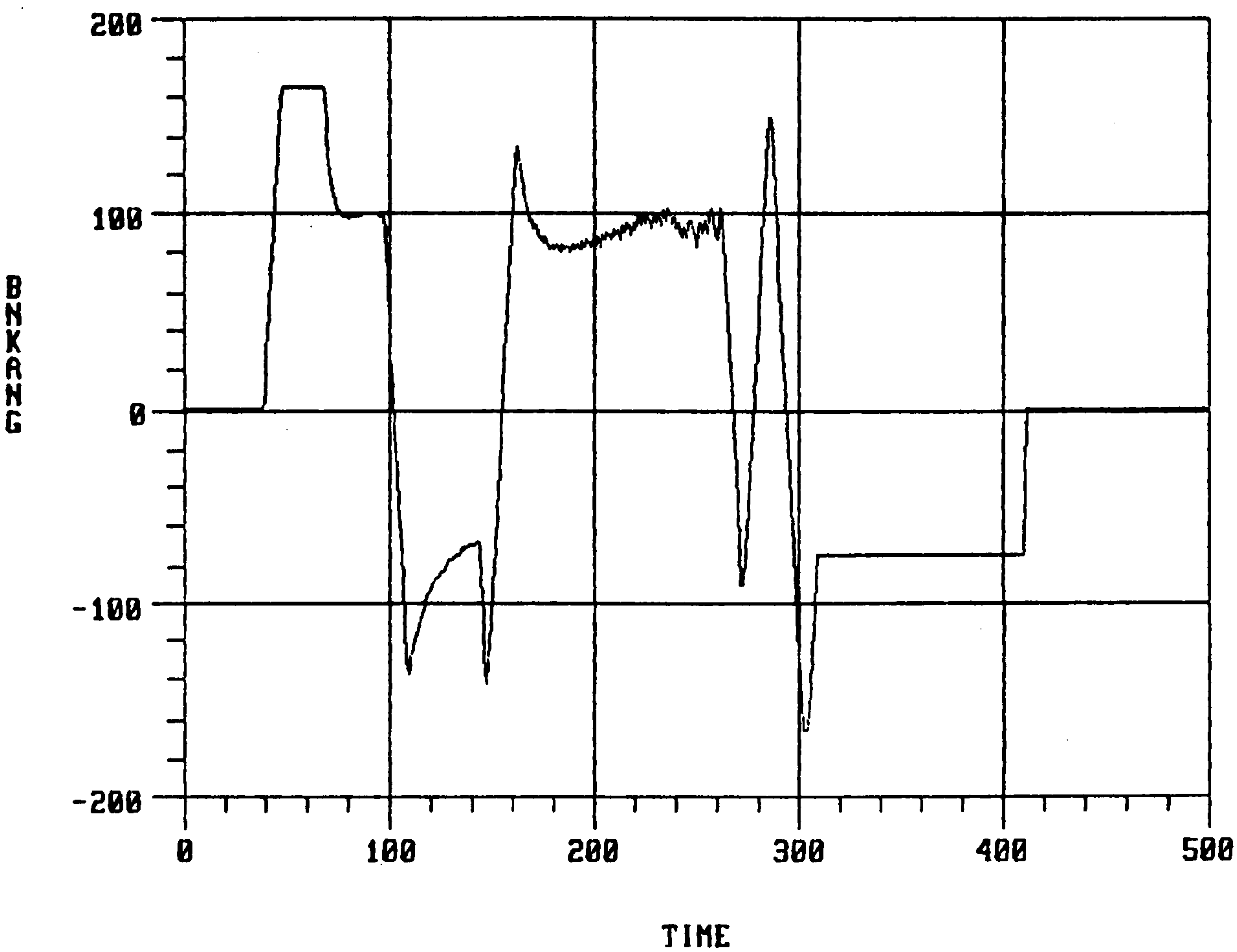
b. Viking transition.

Figure 3. Continued.



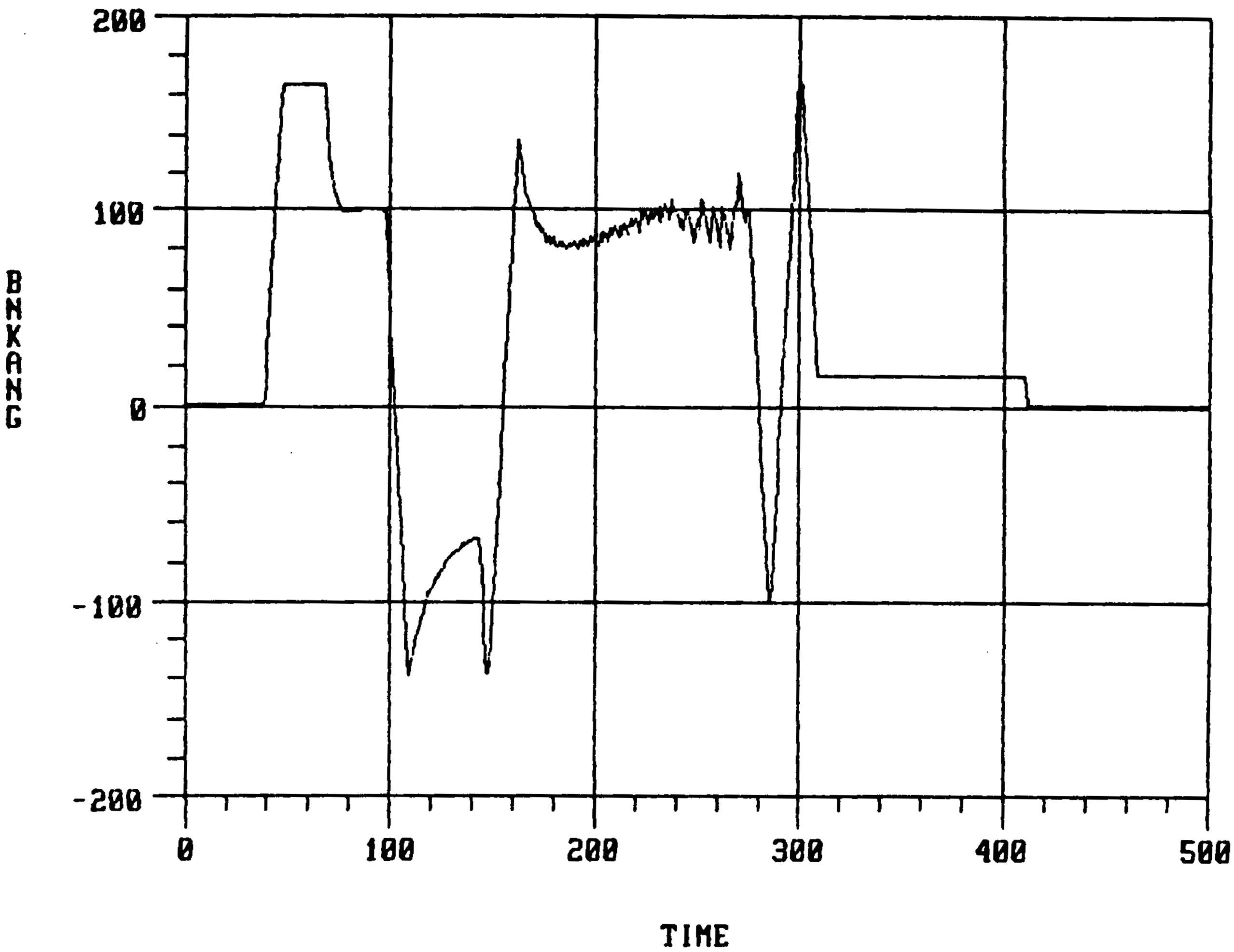
(c) Lockheed transition.

Figure 3. Continued.



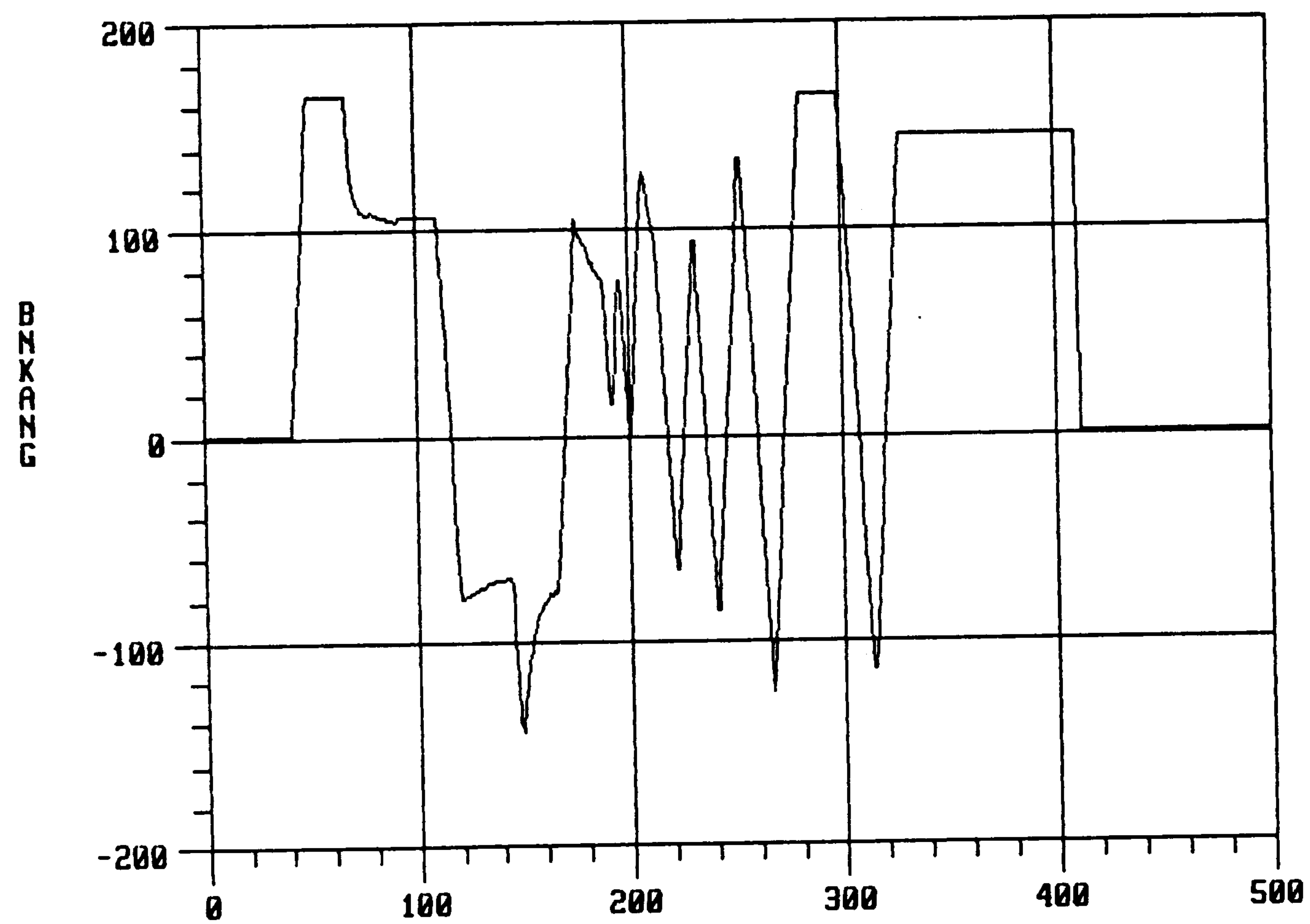
(d) Potter transition.

Figure 3. Continued.



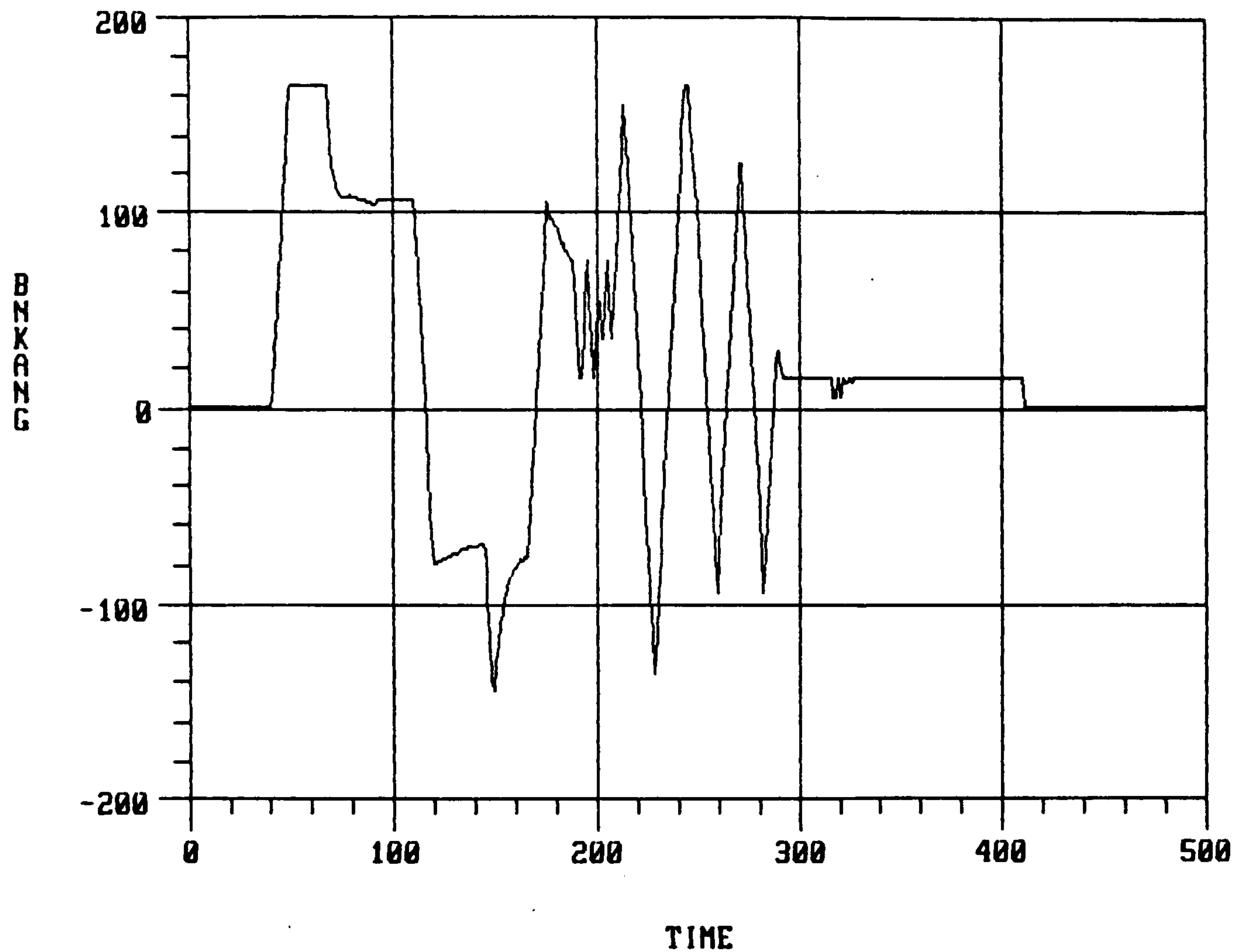
(e) Shock Reynolds transition.

Figure 3. Concluded.



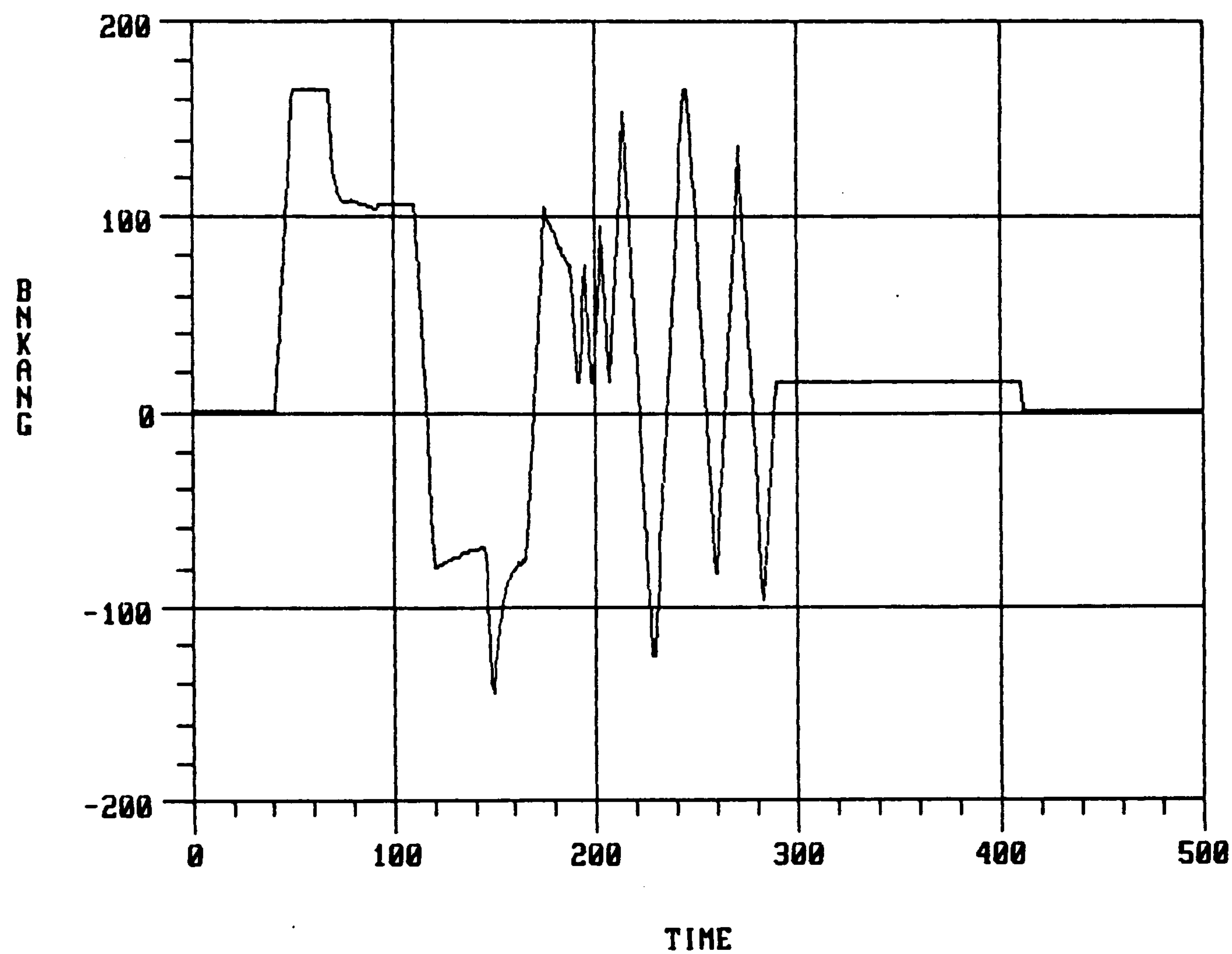
(a) No transition.

Figure 4. Bank angle time history for first "plateau" 20-second guidance modification and 1962 atmosphere.



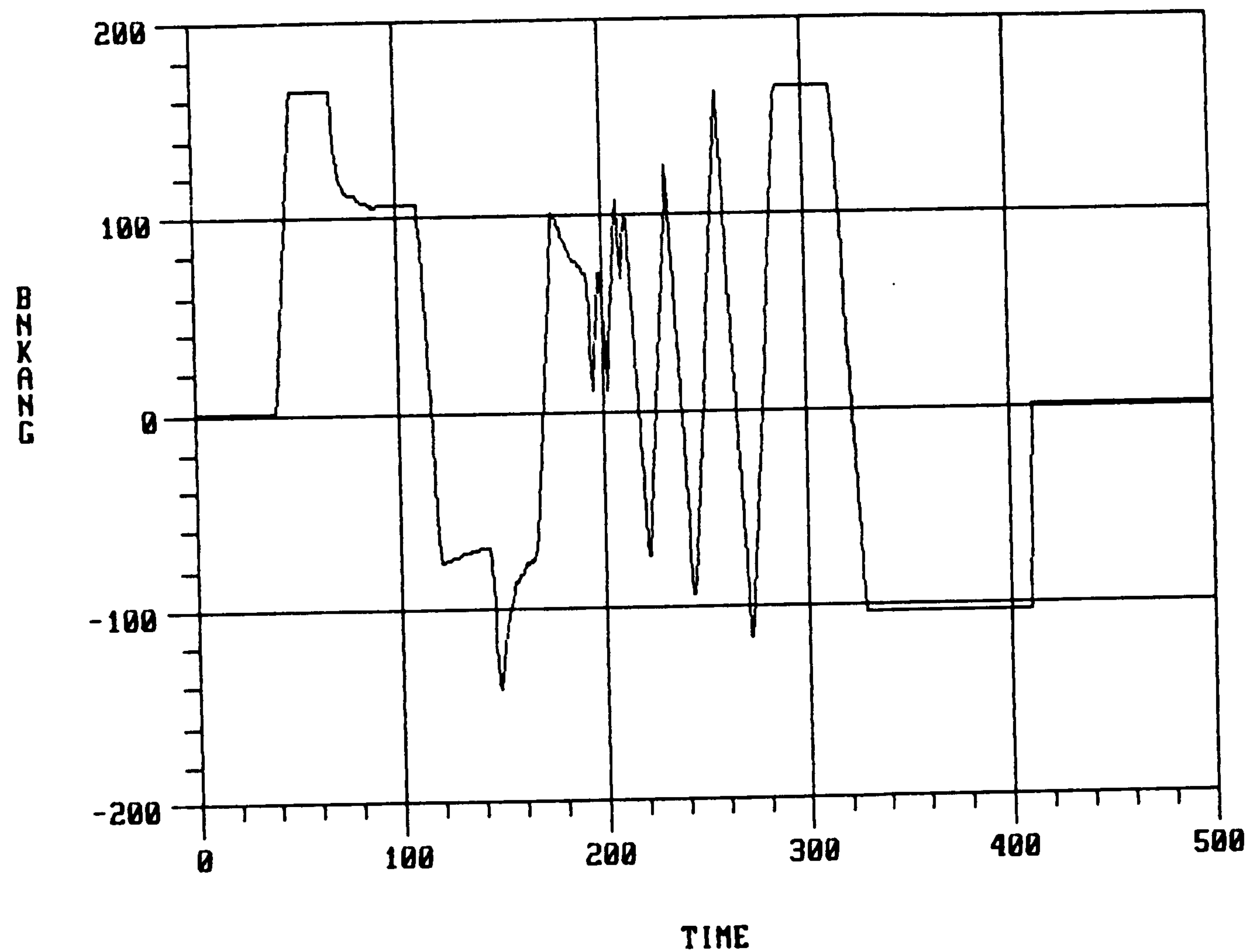
(b) VIKING TRANSITION

Figure 4. Continued.



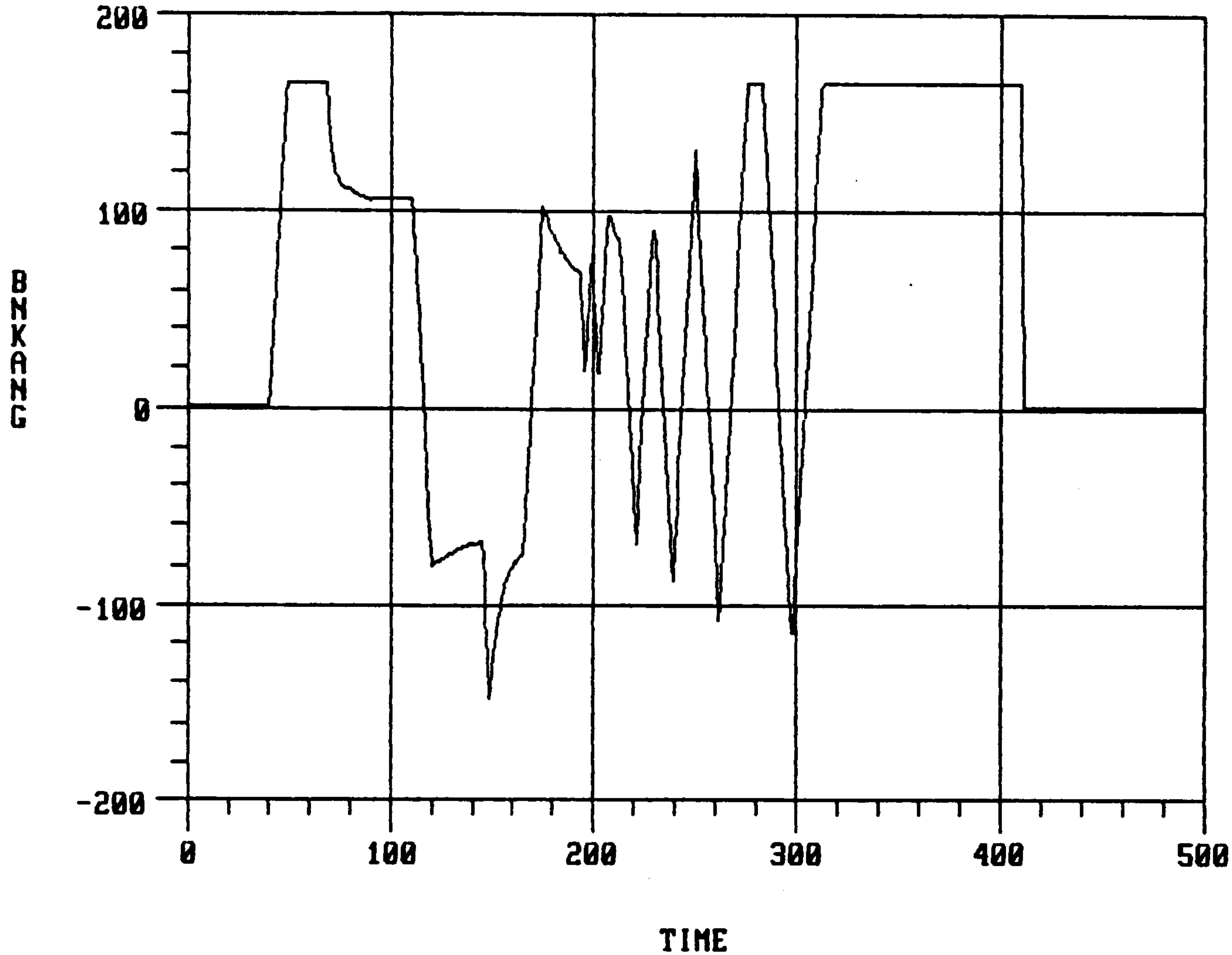
(c) Lockheed transition.

Figure 4. Continued.



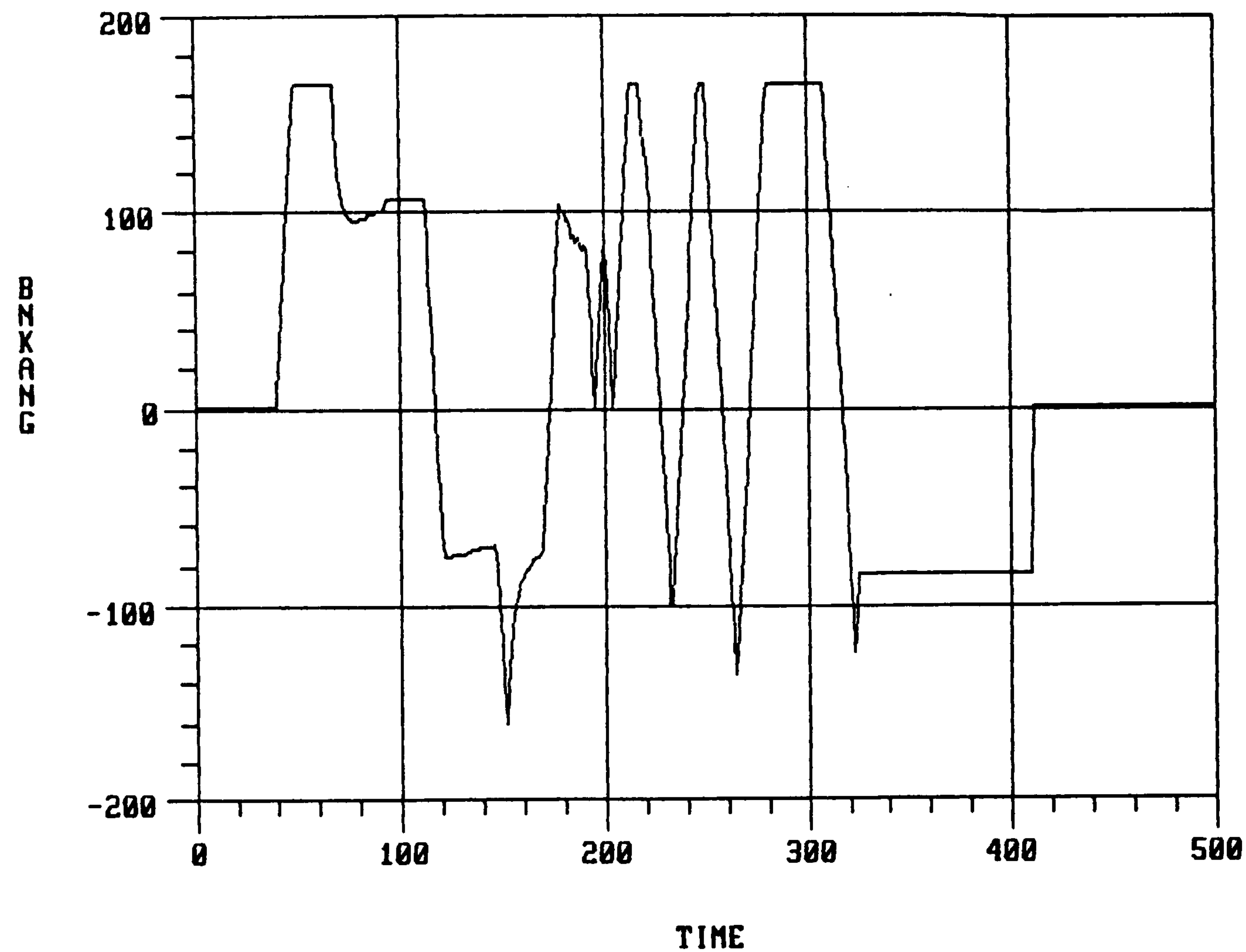
(d) Potter transition.

Figure 4. Continued.



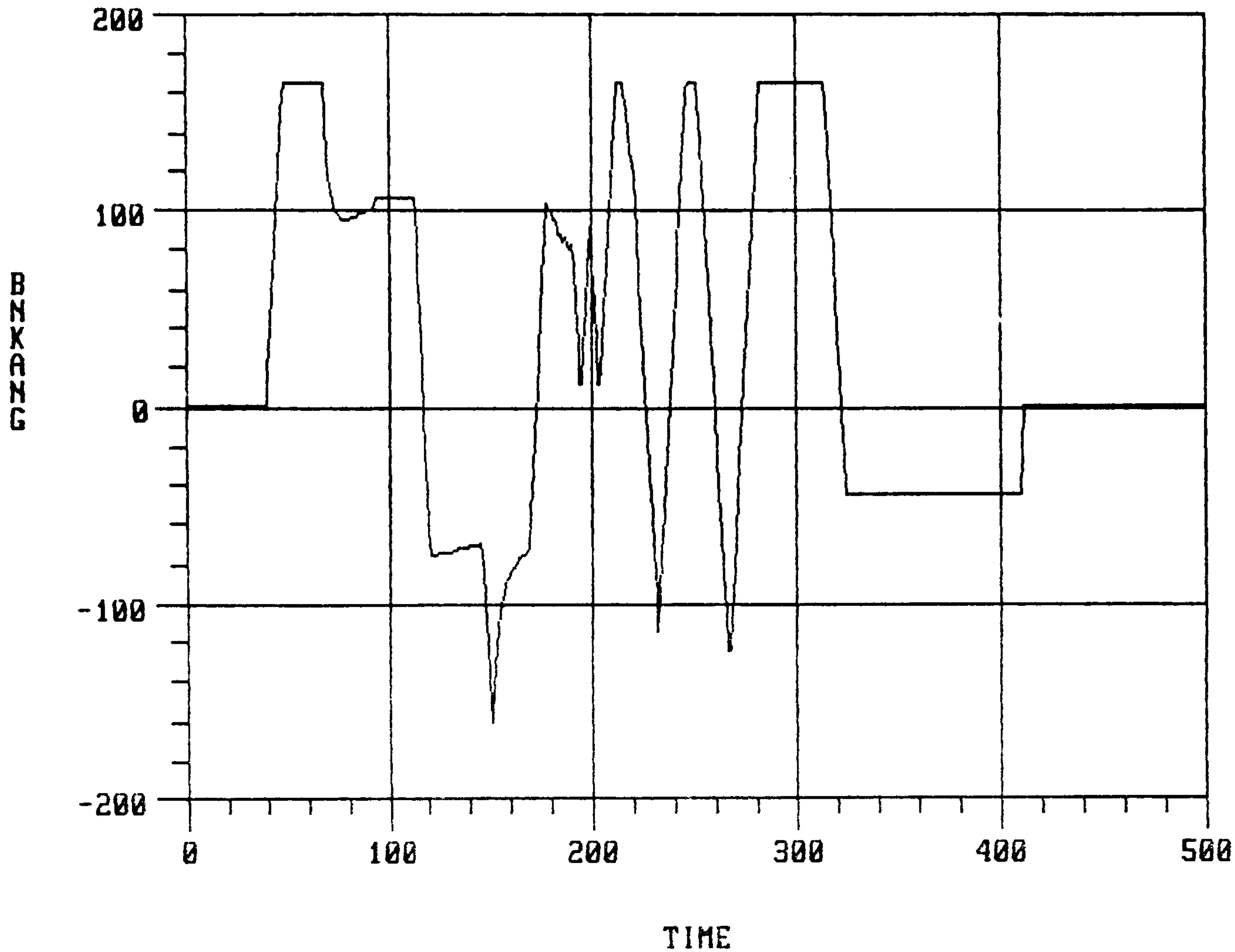
(e) Shock Reynolds number transition.

Figure 4. Concluded.



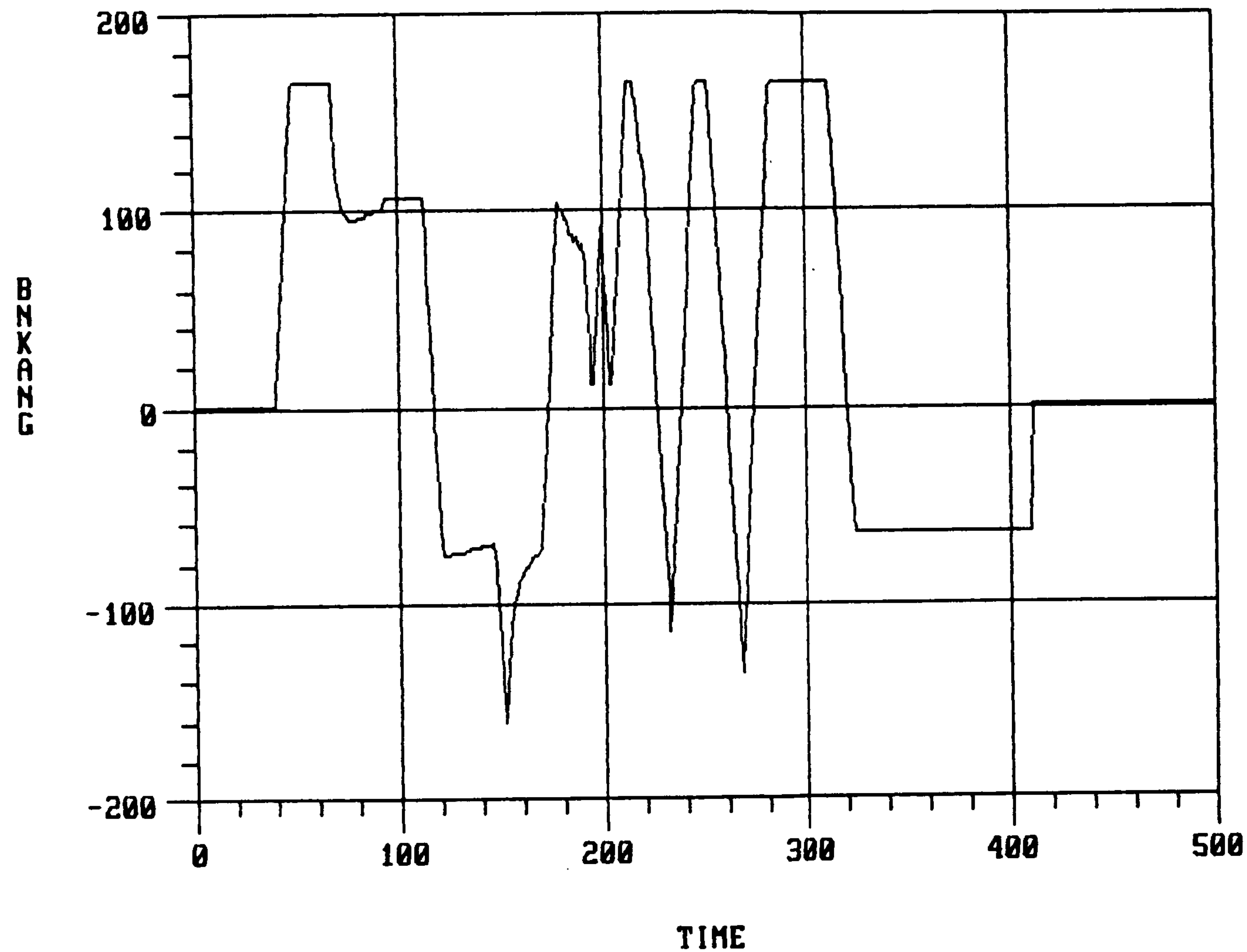
(a) No transition.

Figure 5. Bank angle time history for first "plateau" 20-second guidance modification and 1976 atmosphere.



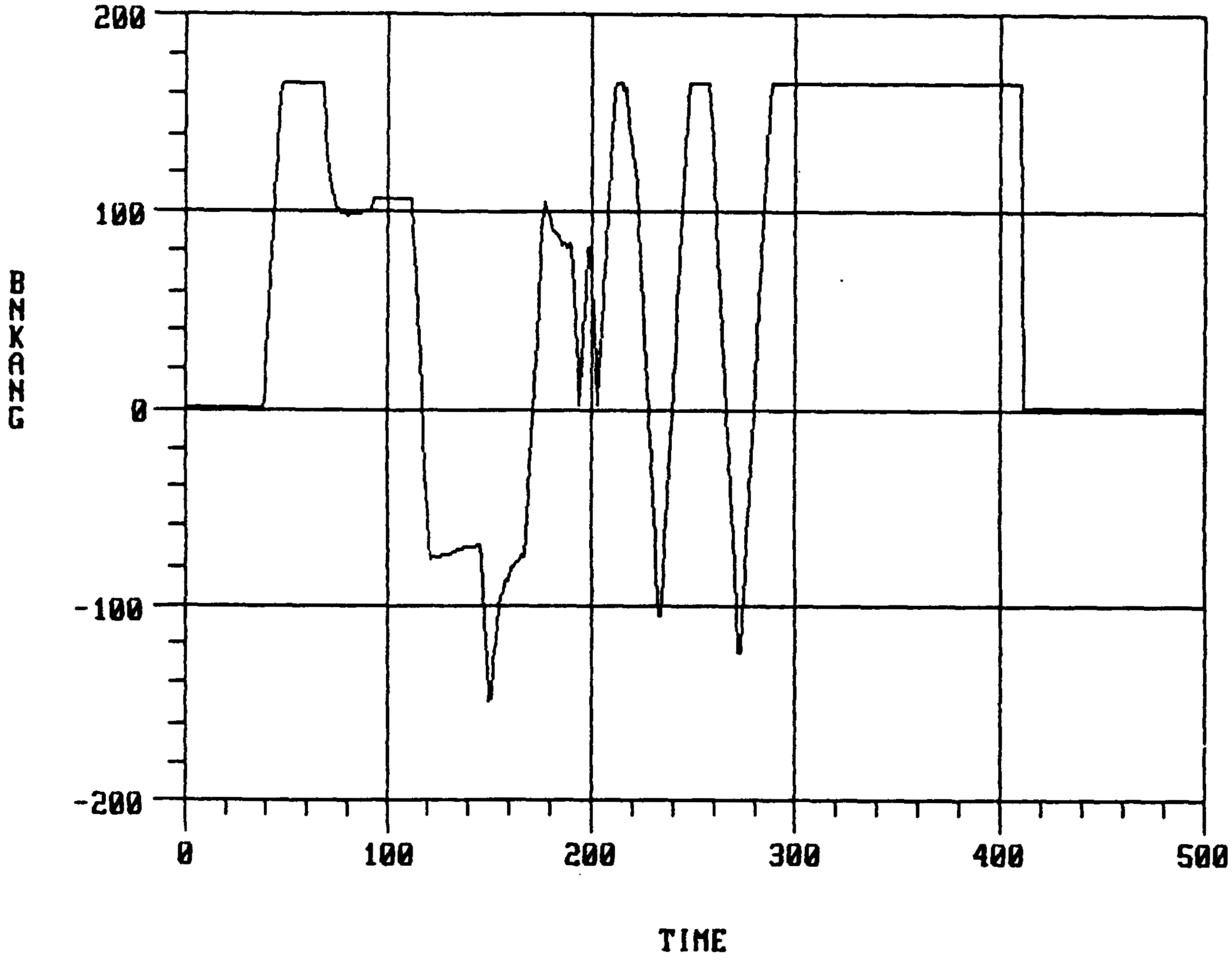
(b) Viking transition.

Figure 5. Continued.



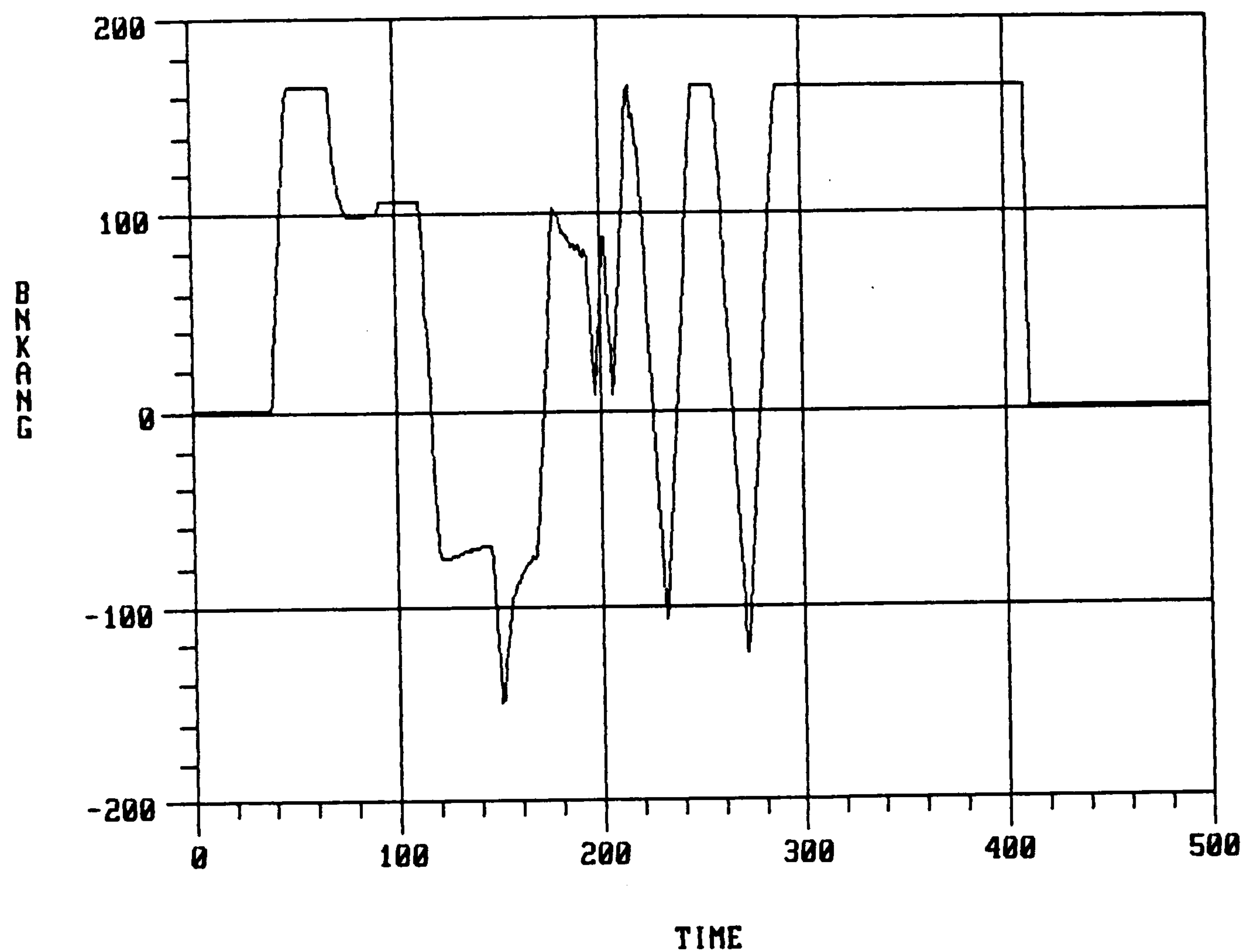
(c) Lockheed transition.

Figure 5. Continued.



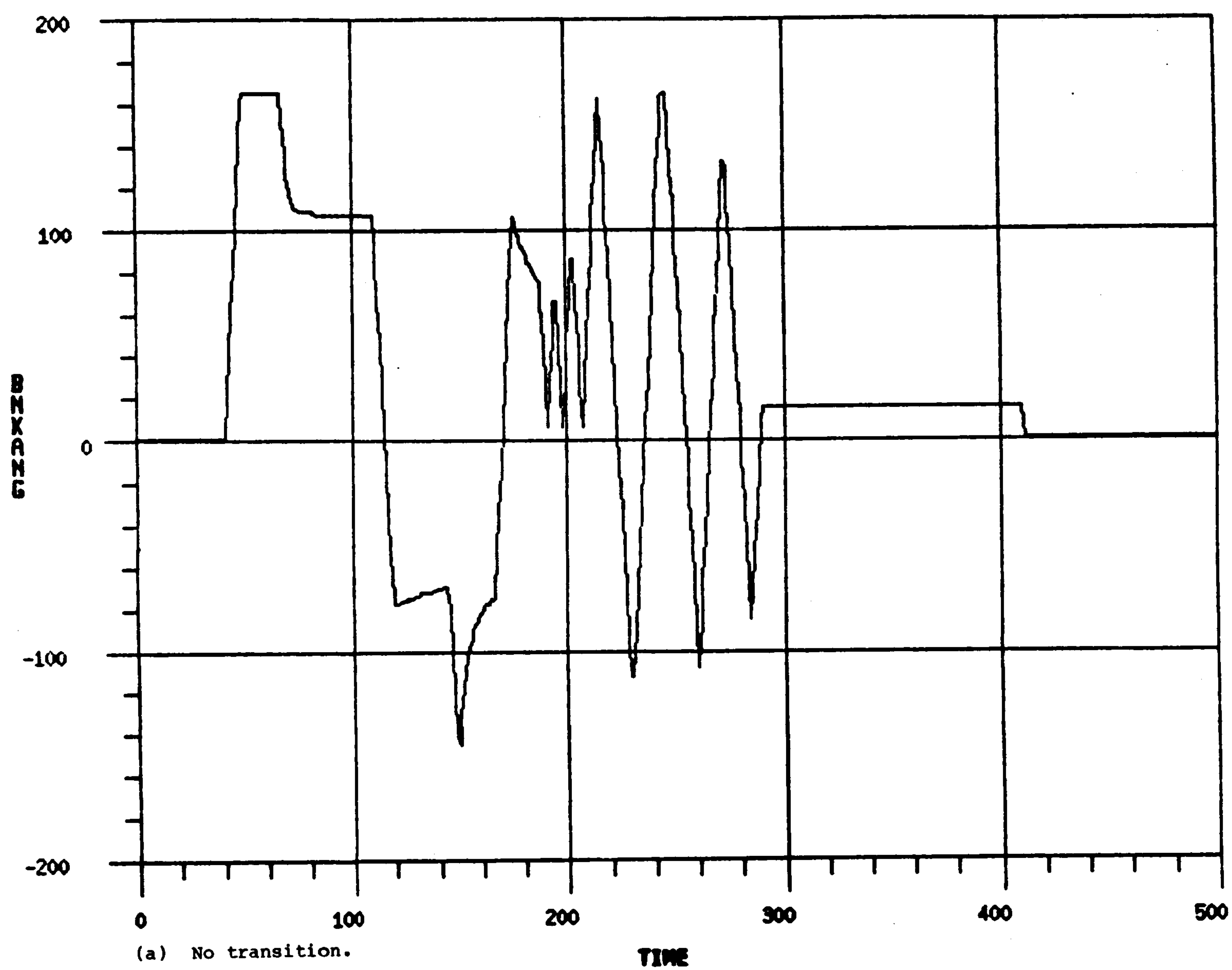
(d) Potter transition.

Figure 5. Continued.



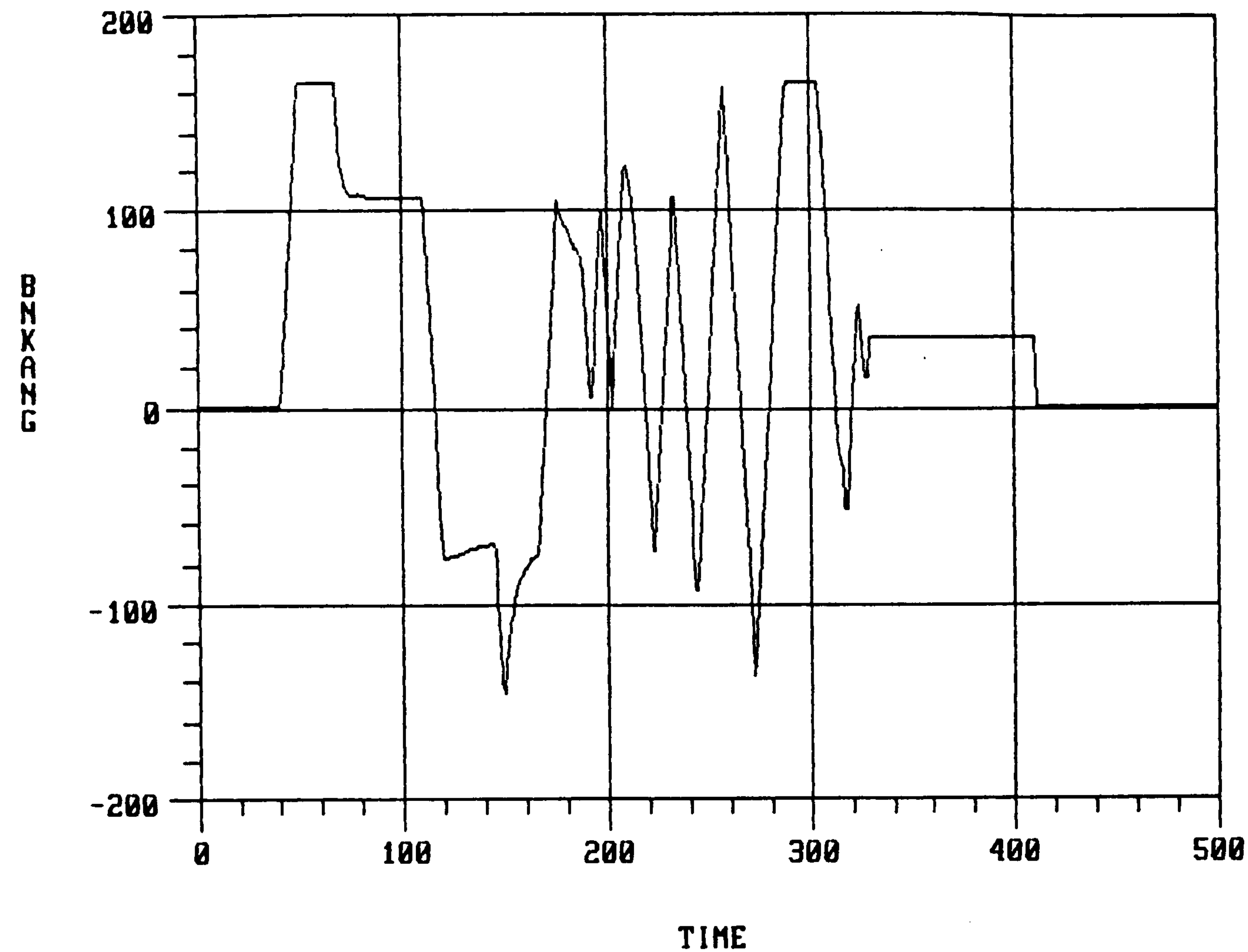
(e) Shock Reynolds transition.

Figure 5. Concluded.



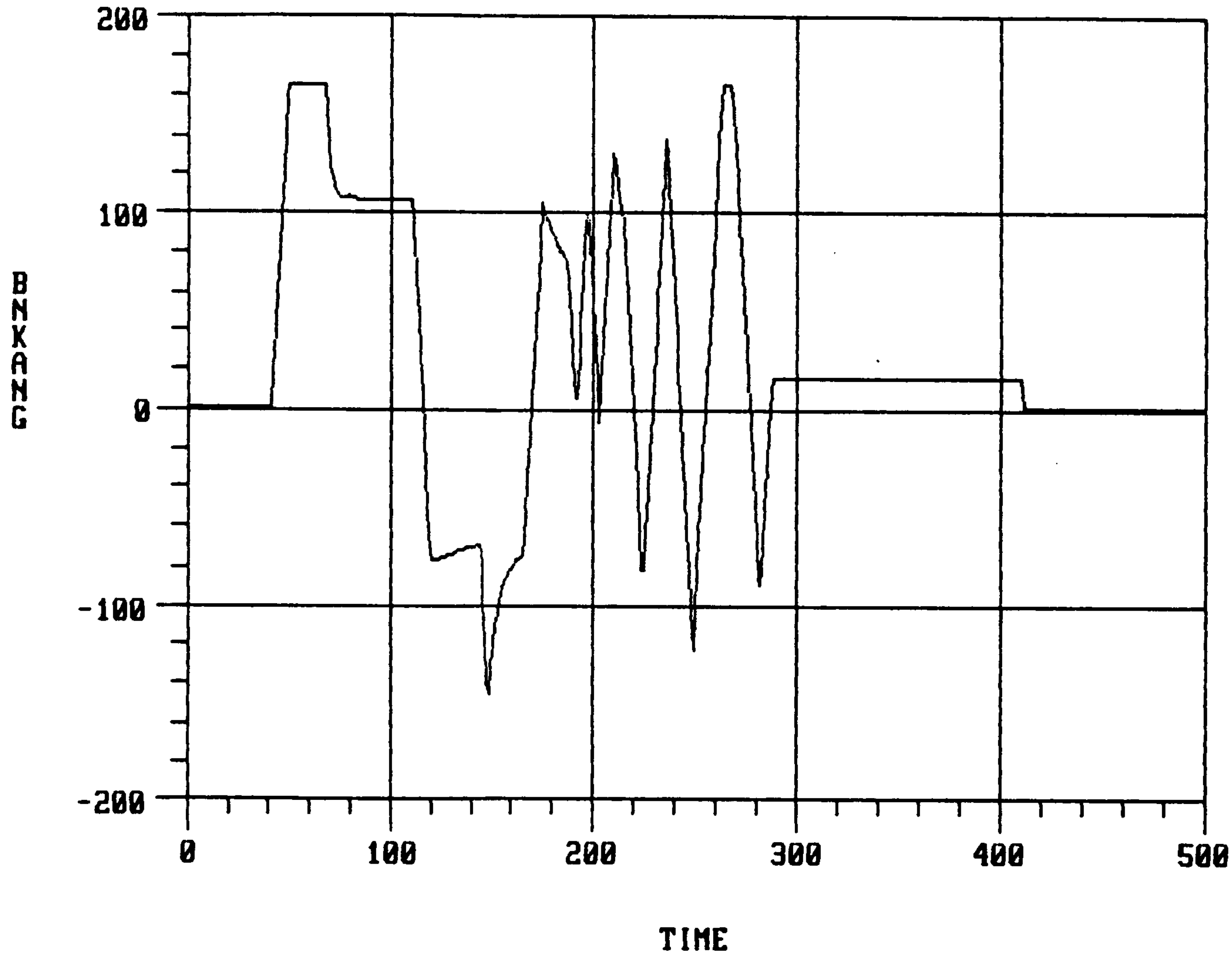
(a) No transition.

Figure 6. Bank angle time history for first "plateau" 30-second guidance modification and 1962 atmosphere.



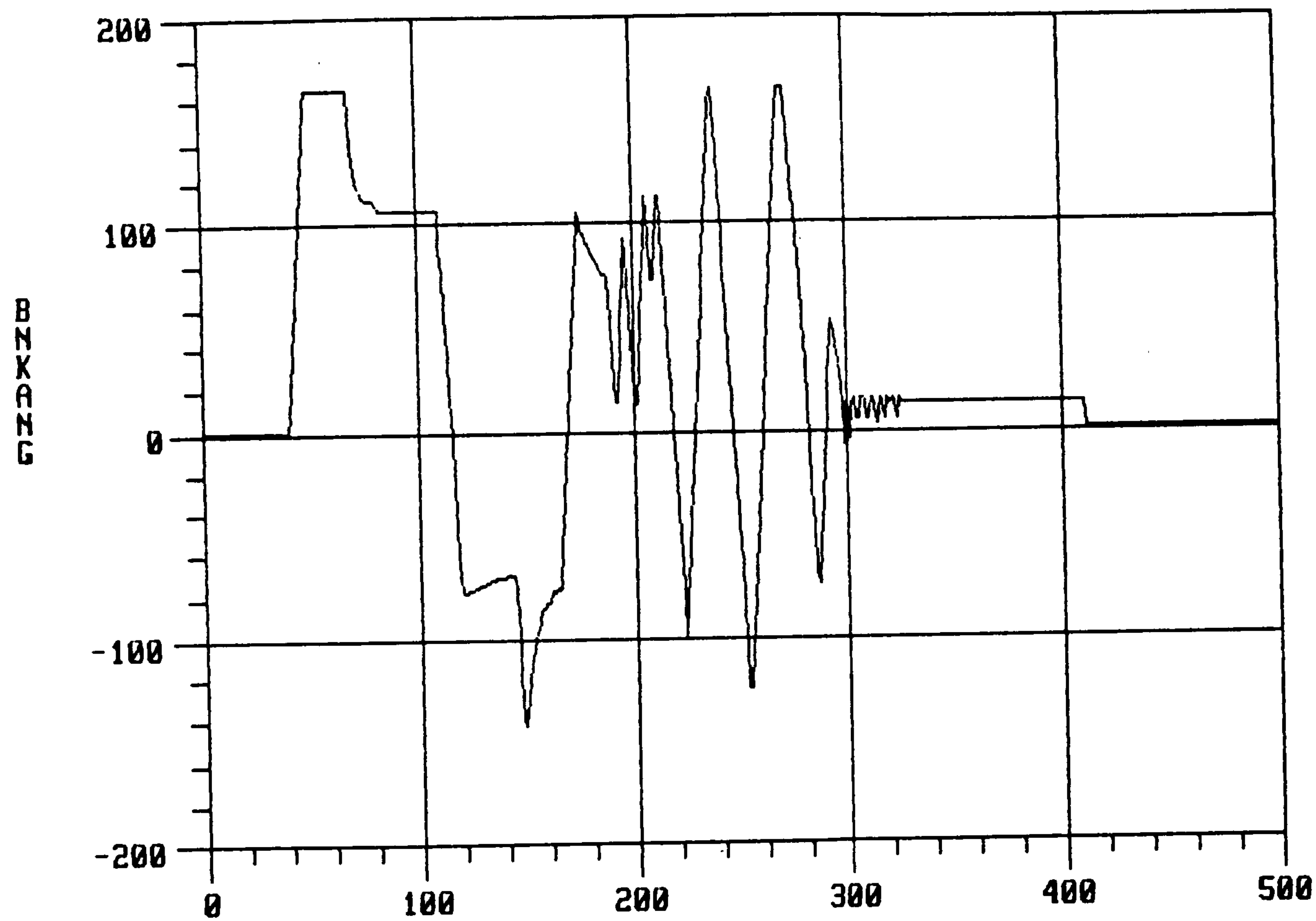
(b) Viking transition.

Figure 6. Continued.



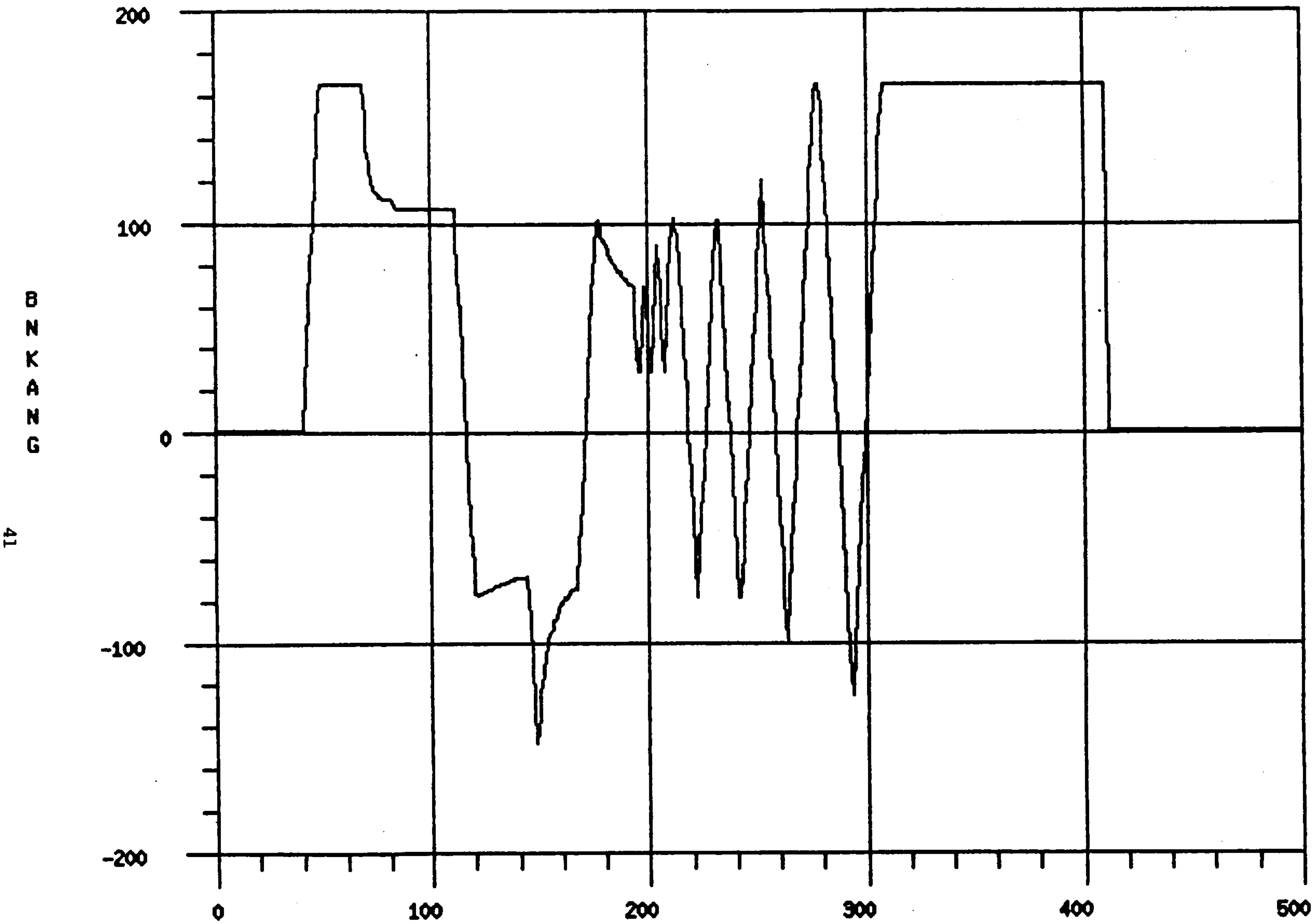
(c) Lockheed transition.

Figure 6. Continued.



(d) Potter transition.

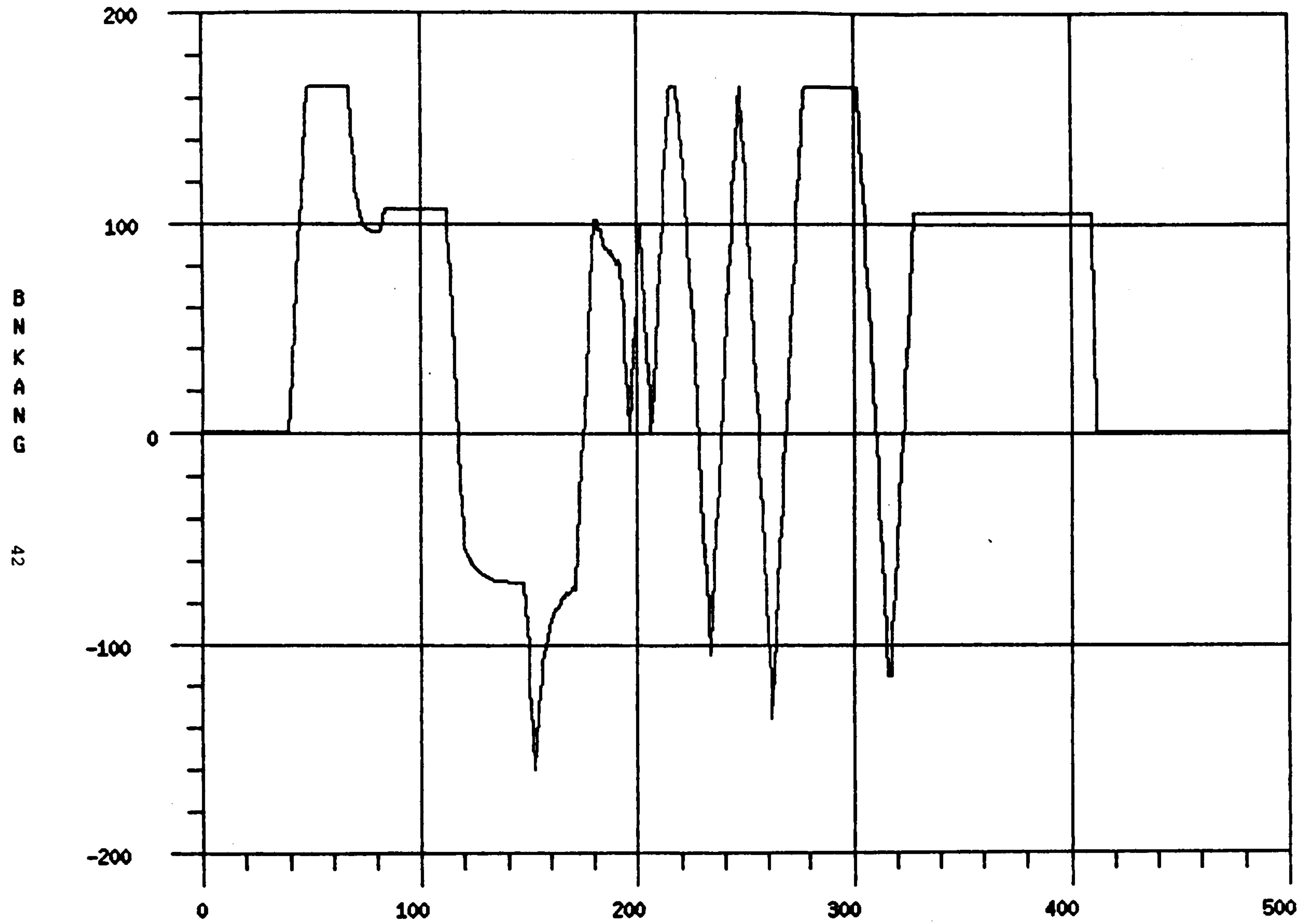
Figure 6. Continued.



(e) Shock Reynolds transition.

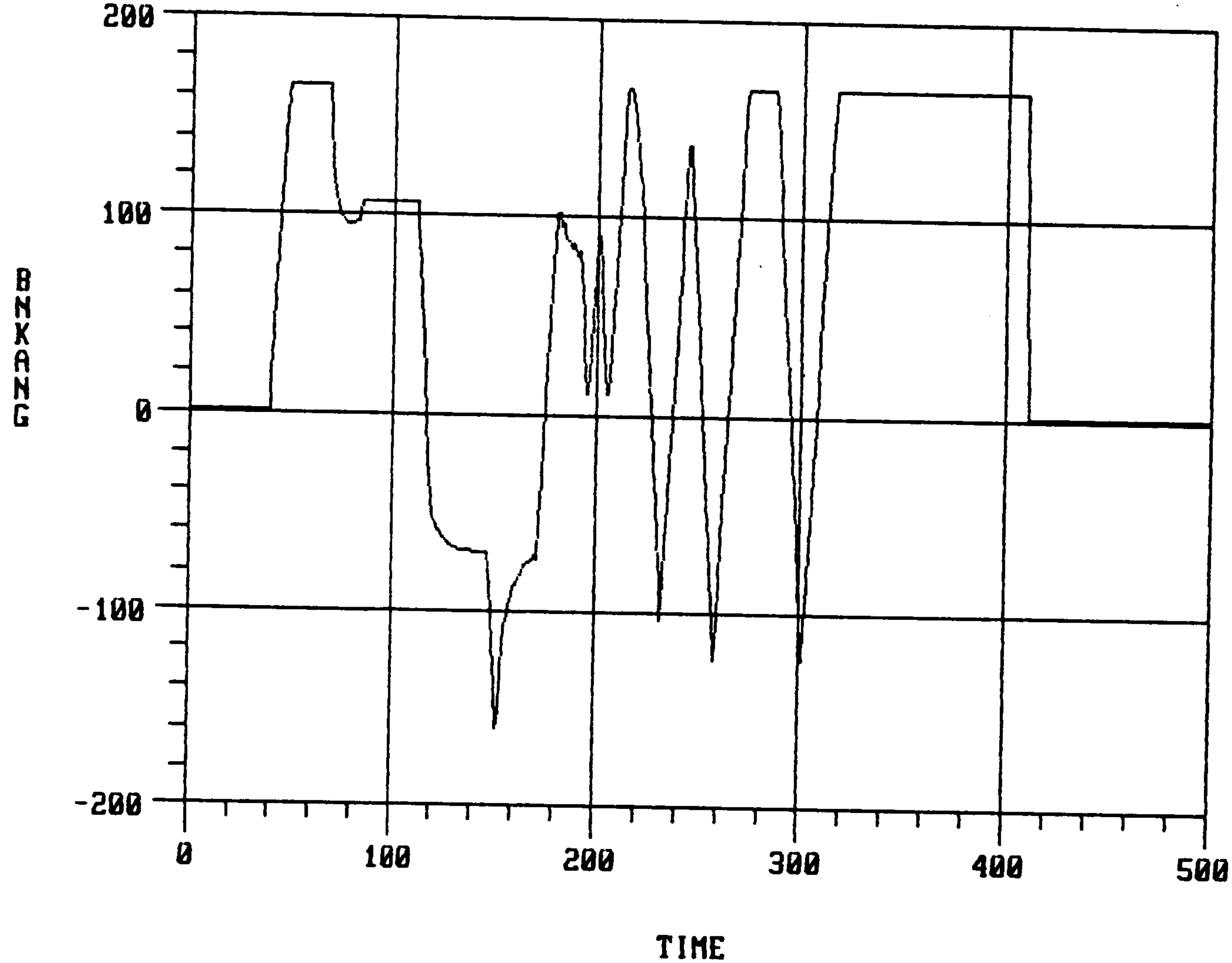
TIME

Figure 6. Concluded.



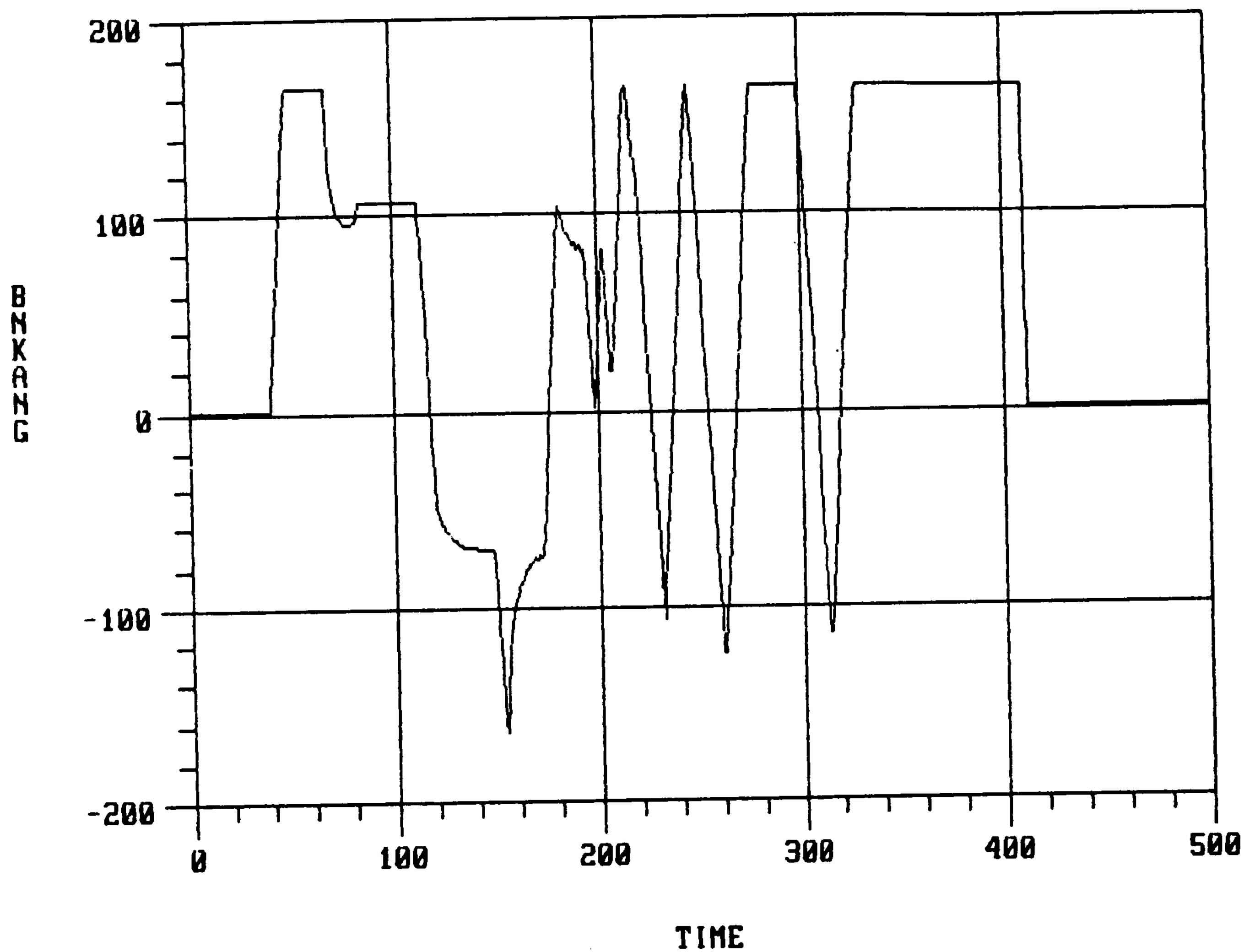
(a) No transition.

Figure 7. Bank angle time history for first "plateau" 30-second guidance modification and 1976 atmospheres.



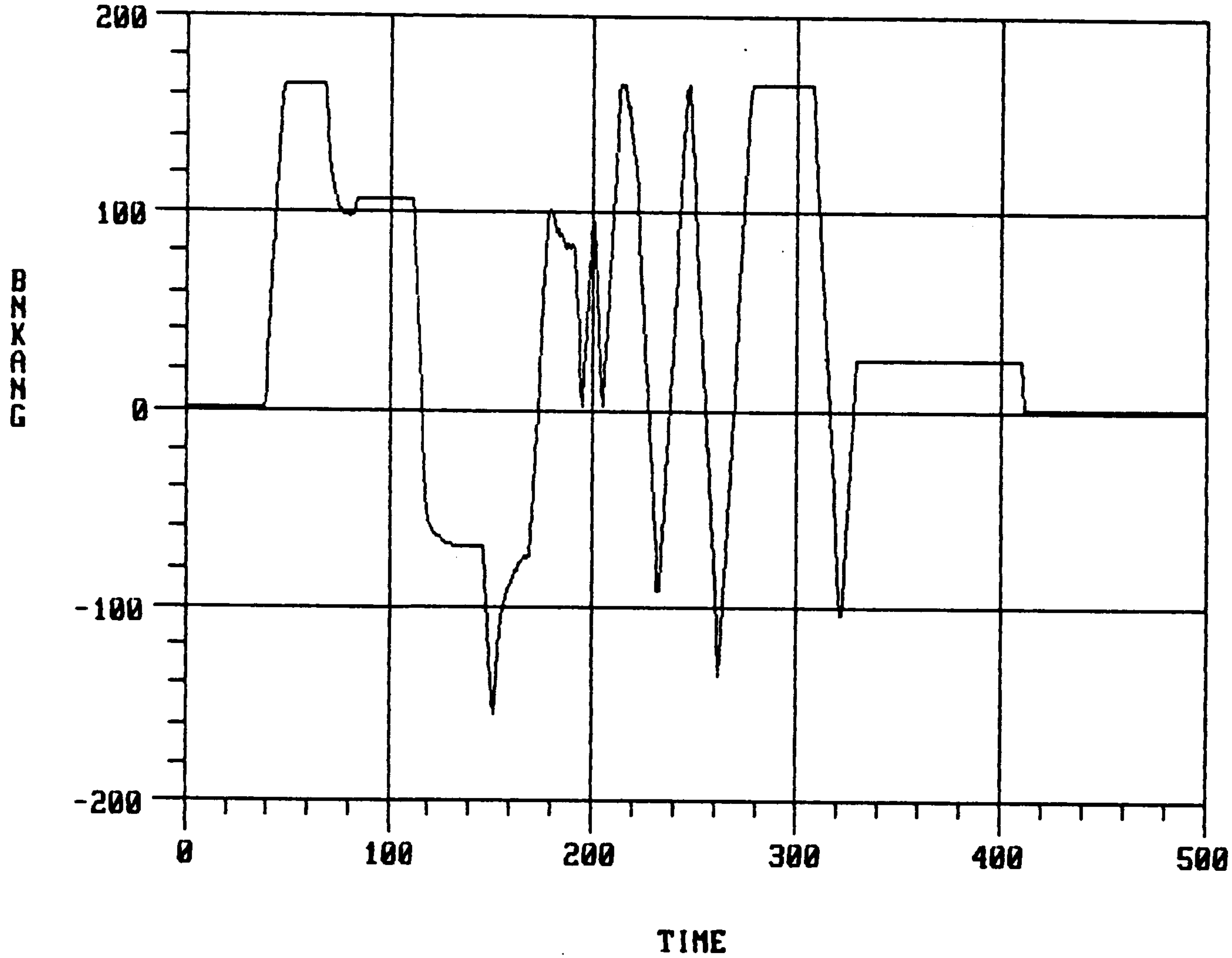
(b) Viking transition.

Figure 7. Continued.



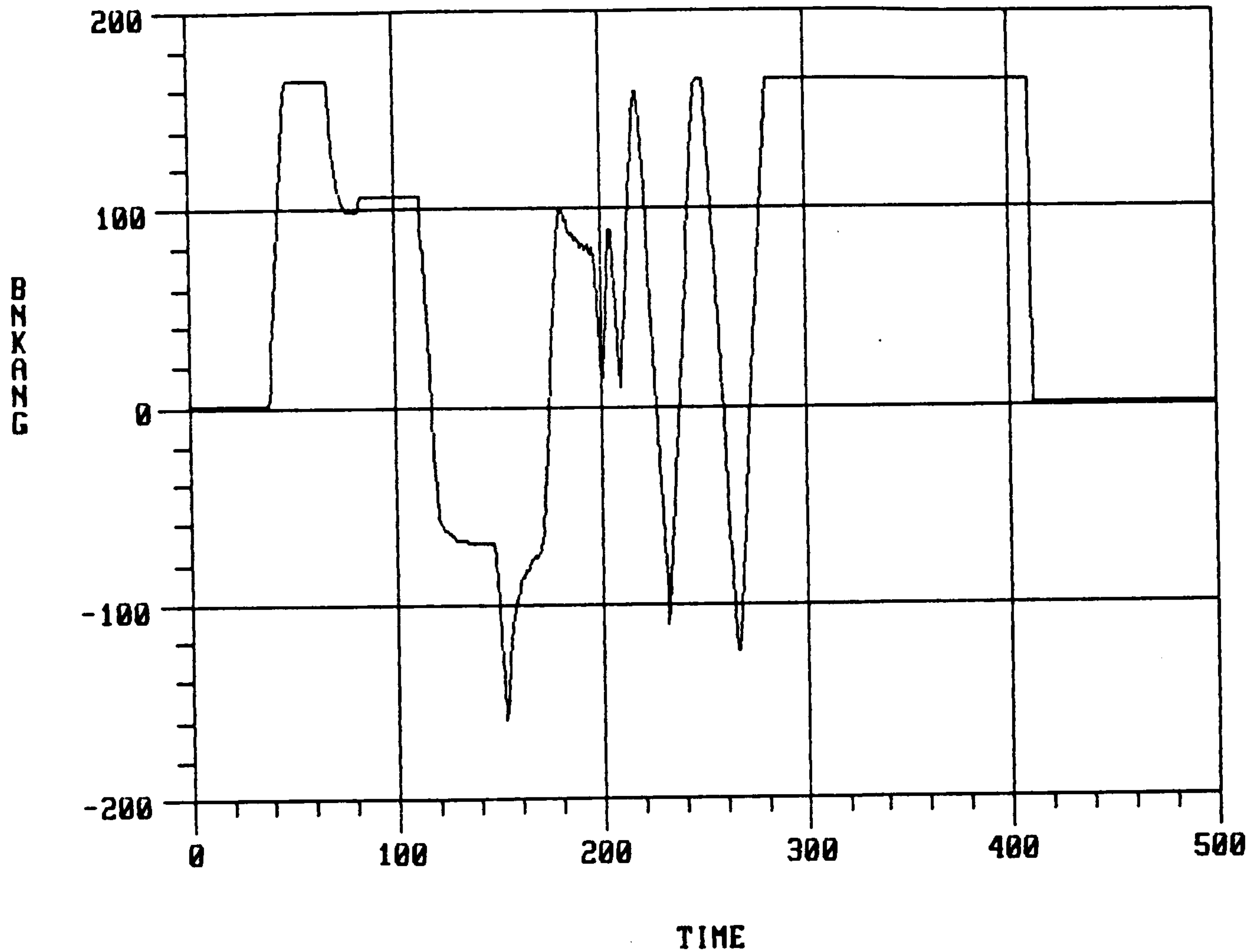
(c) Lockheed transition.

Figure 7. Continued.



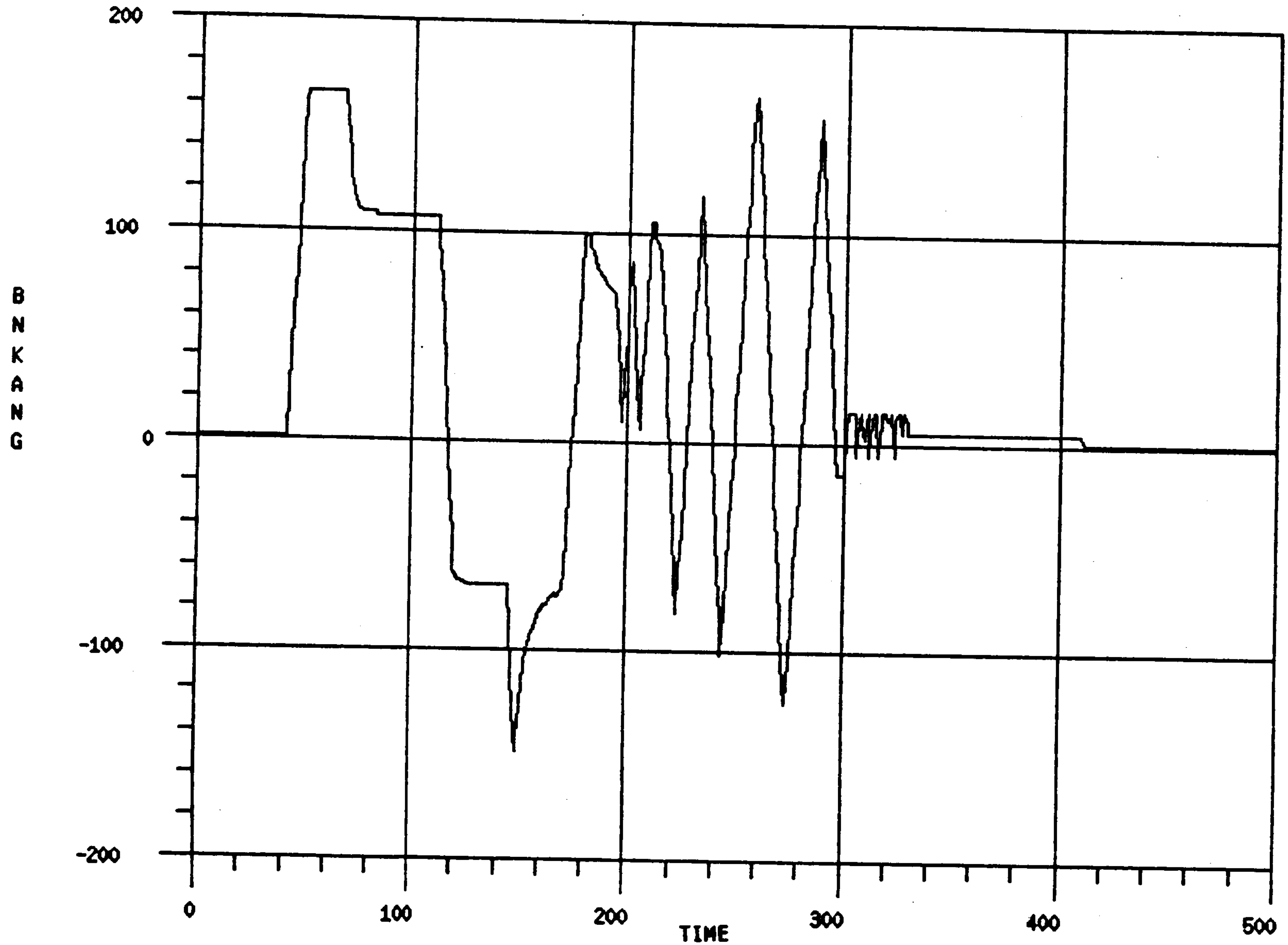
(d) Potter transition.

Figure 7. Continued.



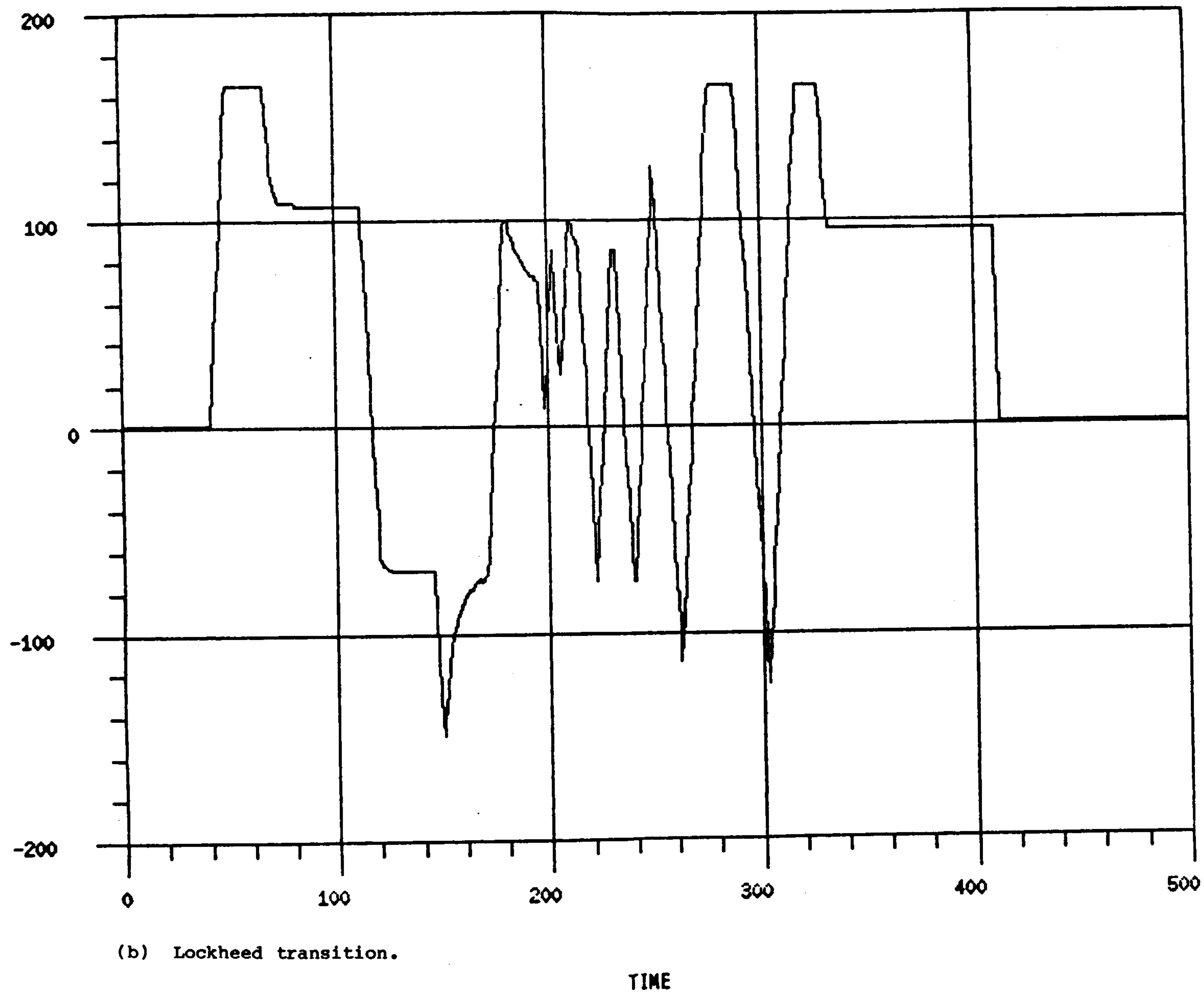
(e) Shock Reynolds transition.

Figure 7. Concluded.



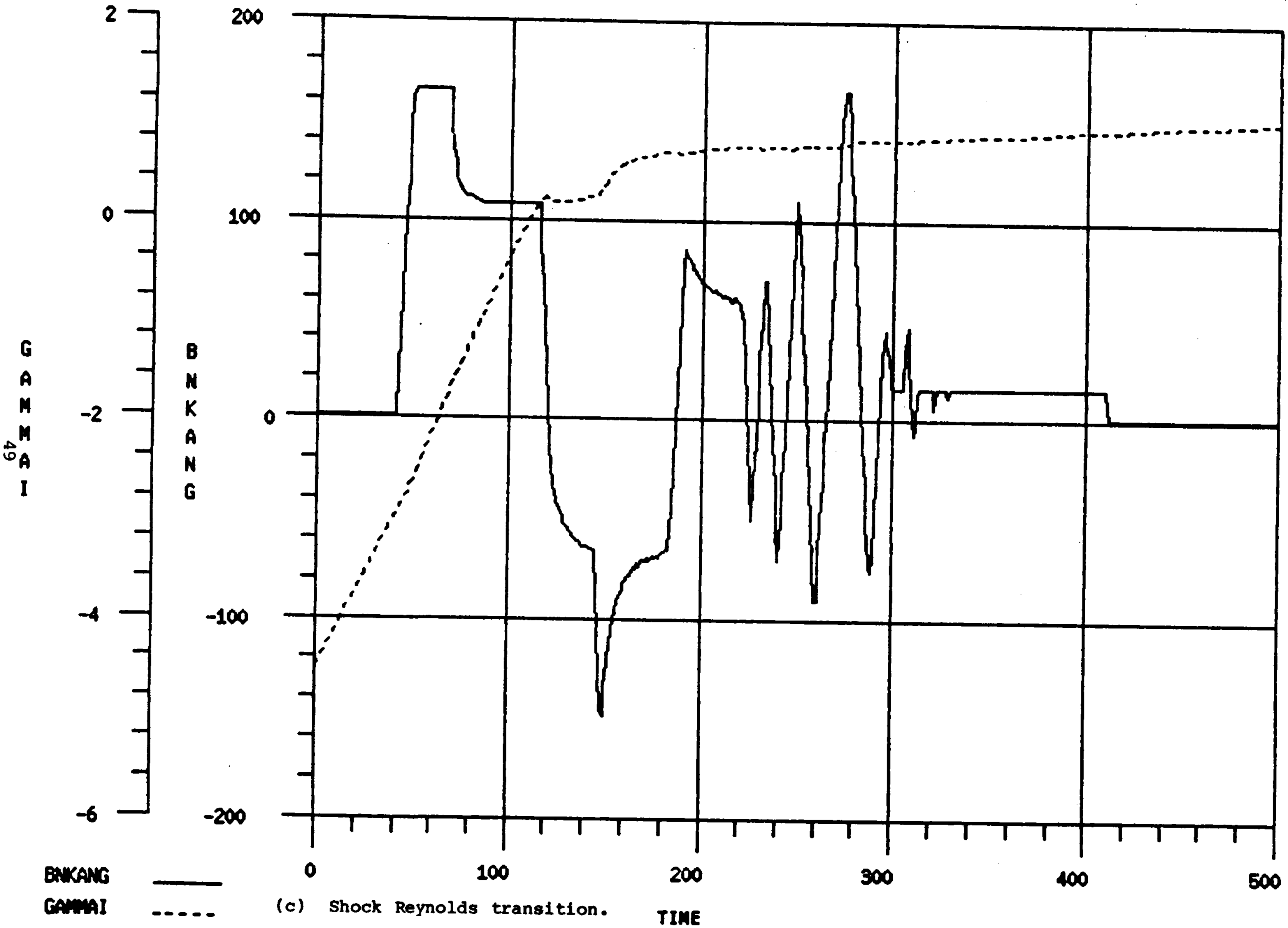
(a) No transition.

Figure 8. Bank angle time history for second "plateau" guidance modification and 1962 atmosphere.



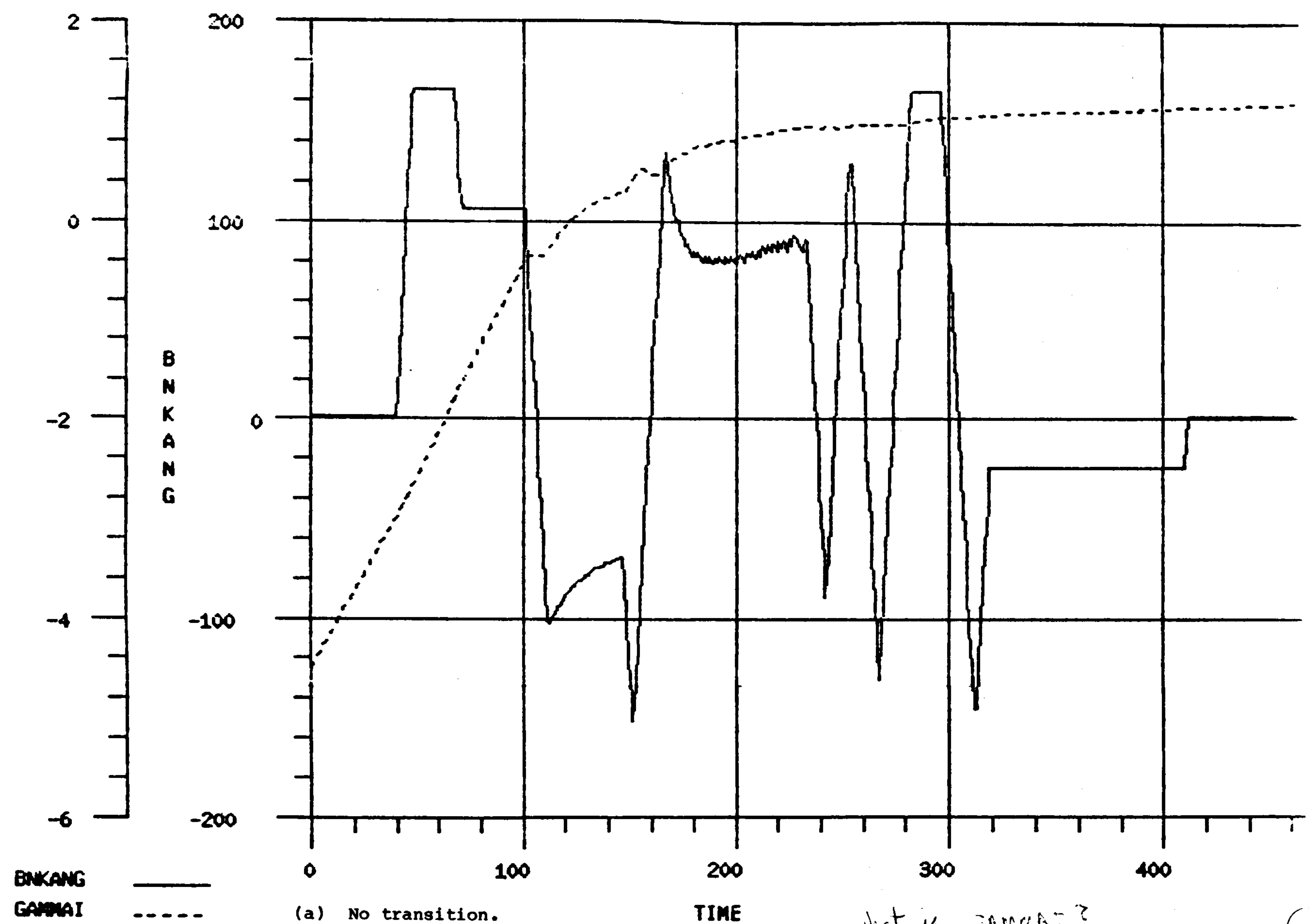
(b) Lockheed transition.

Figure 8. Continued.



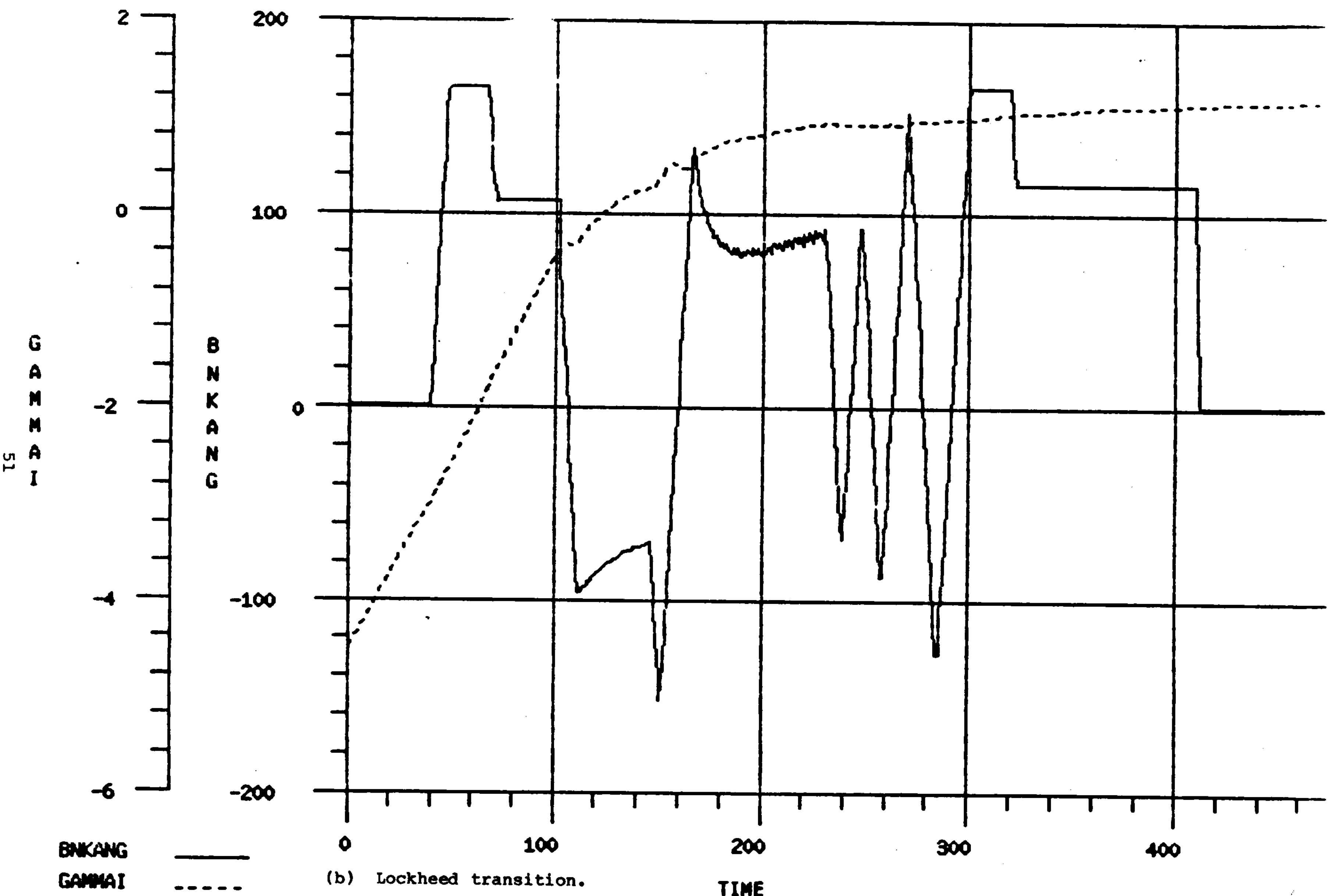
(c) Shock Reynolds transition.

Figure 8. Concluded.



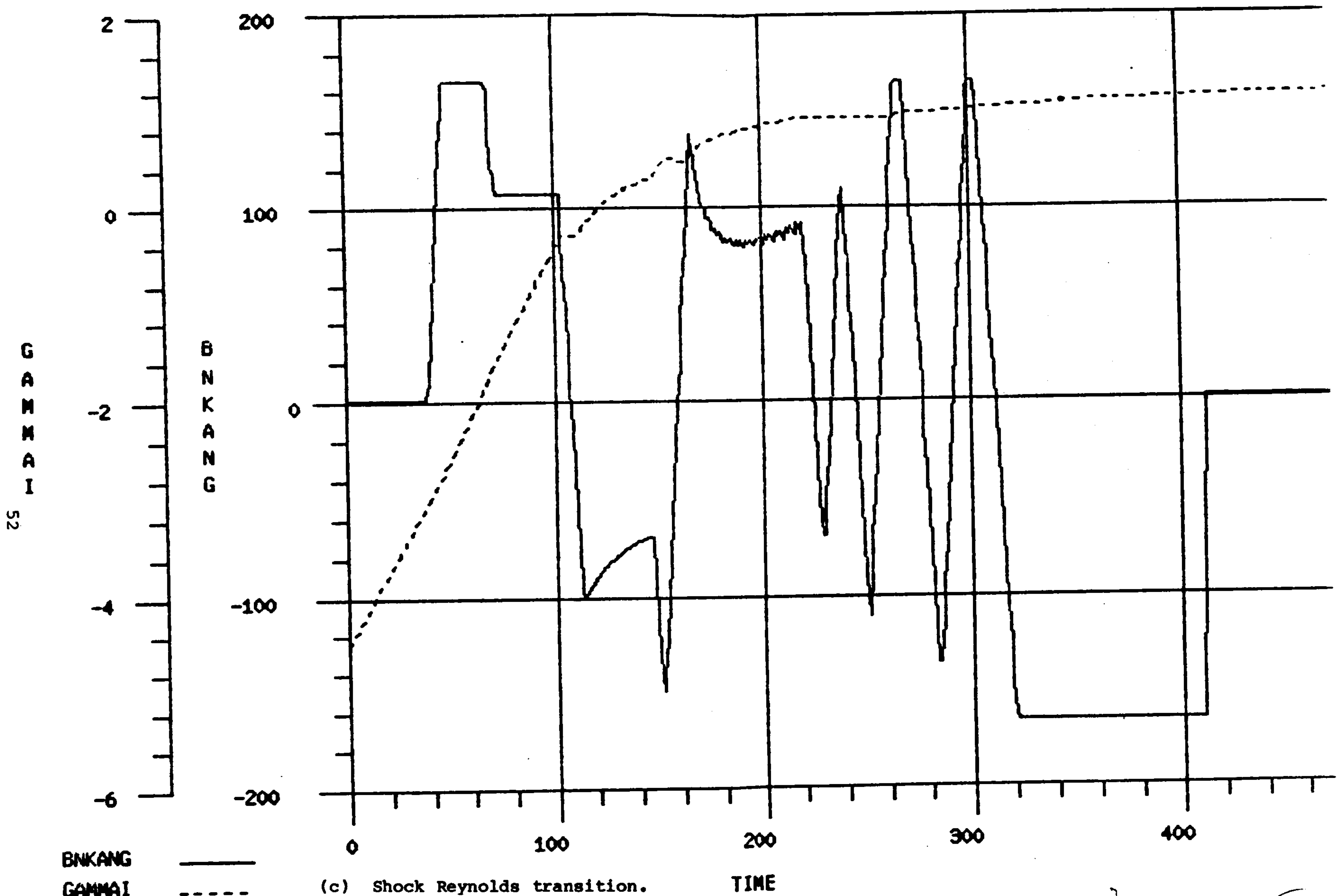
(a) No transition.

Figure 9. Bank angle time history for second "plateau" guidance modification and 1976 atmosphere.



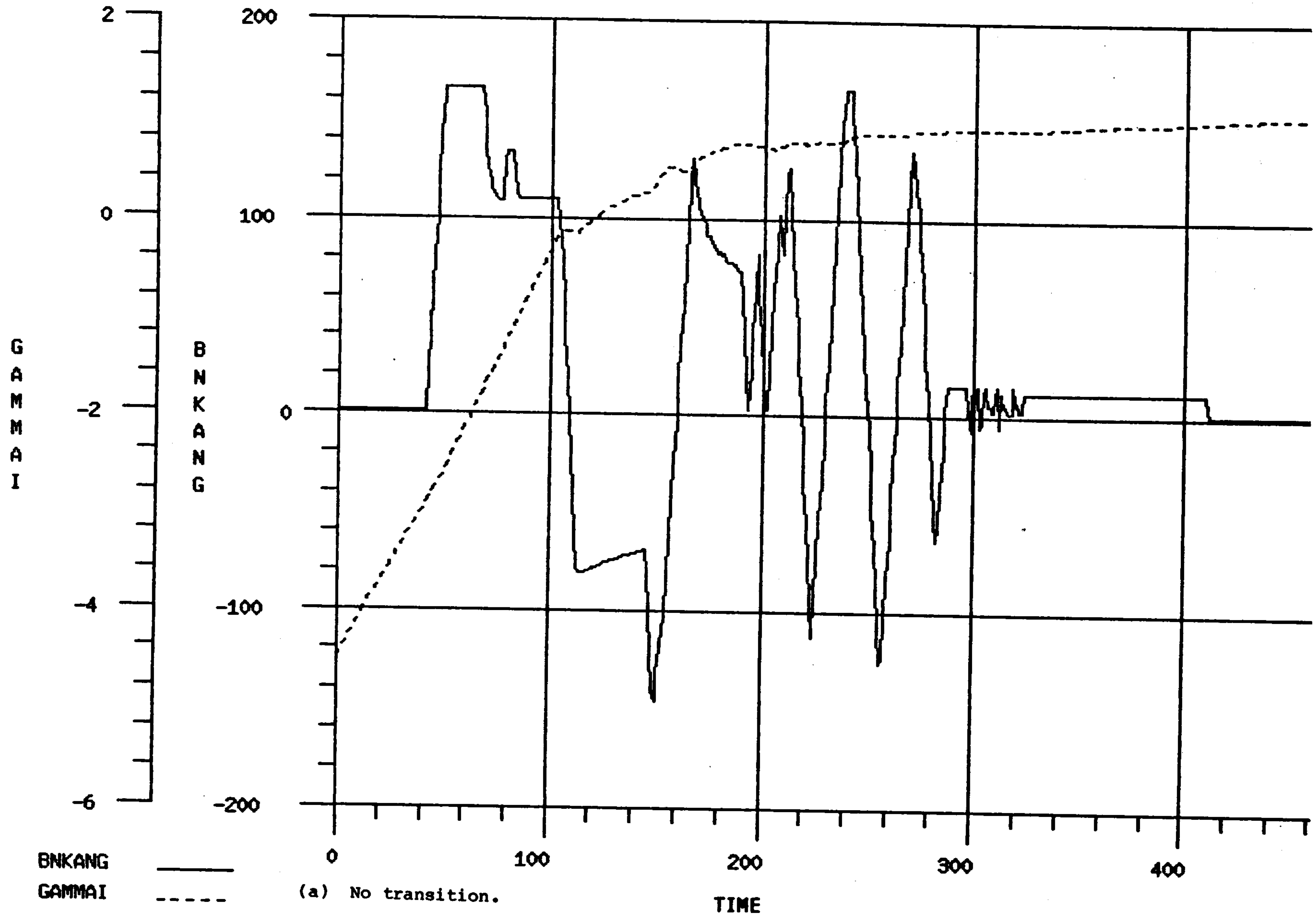
(b) Lockheed transition.

Figure 9. Continued.



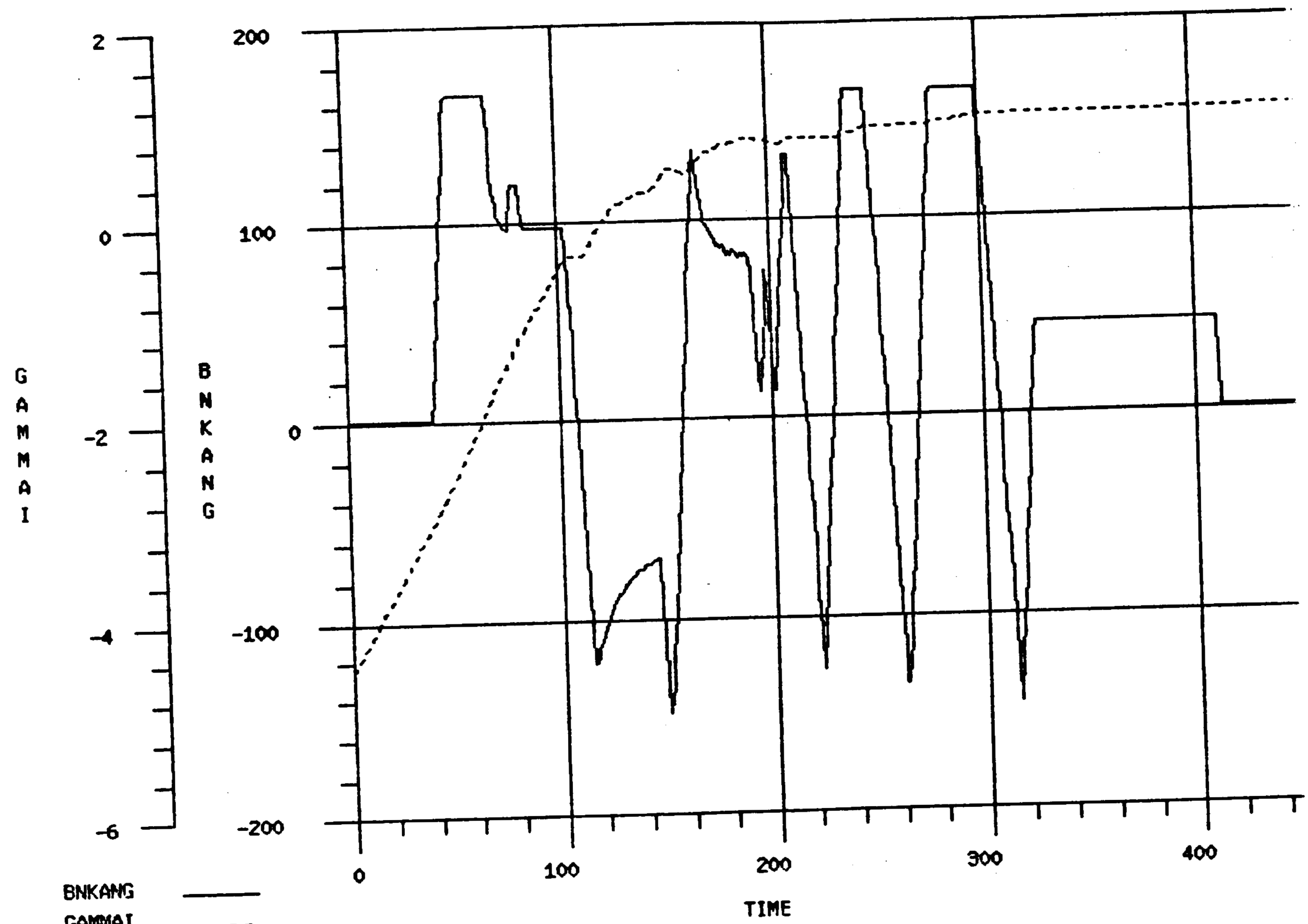
(c) Shock Reynolds transition.

Figure 9. Concluded.



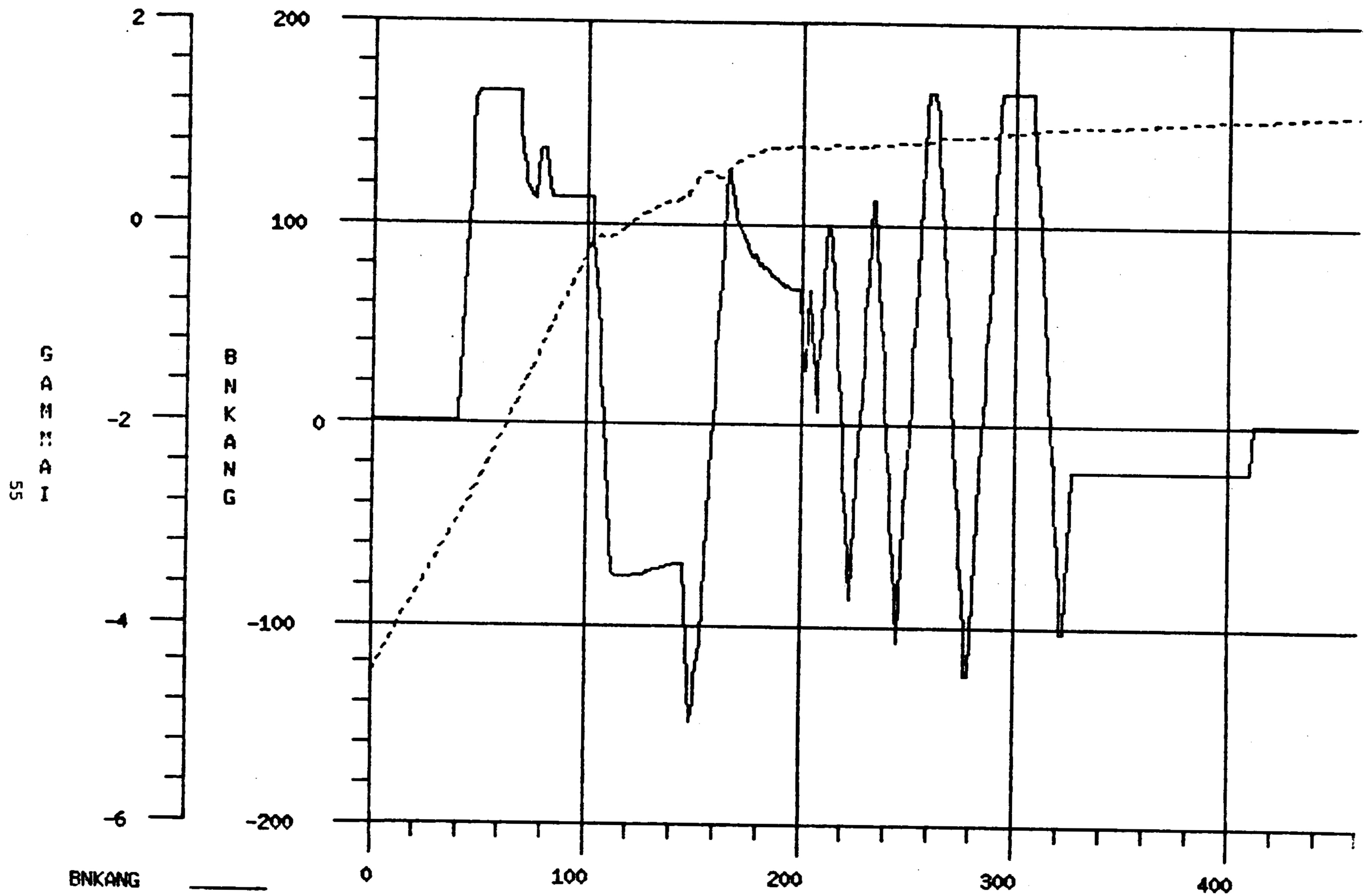
(a) No transition.

Figure 10. Bank angle time history for 25 degree out-in guidance modification with 20-second hold and 1962 atmosphere.



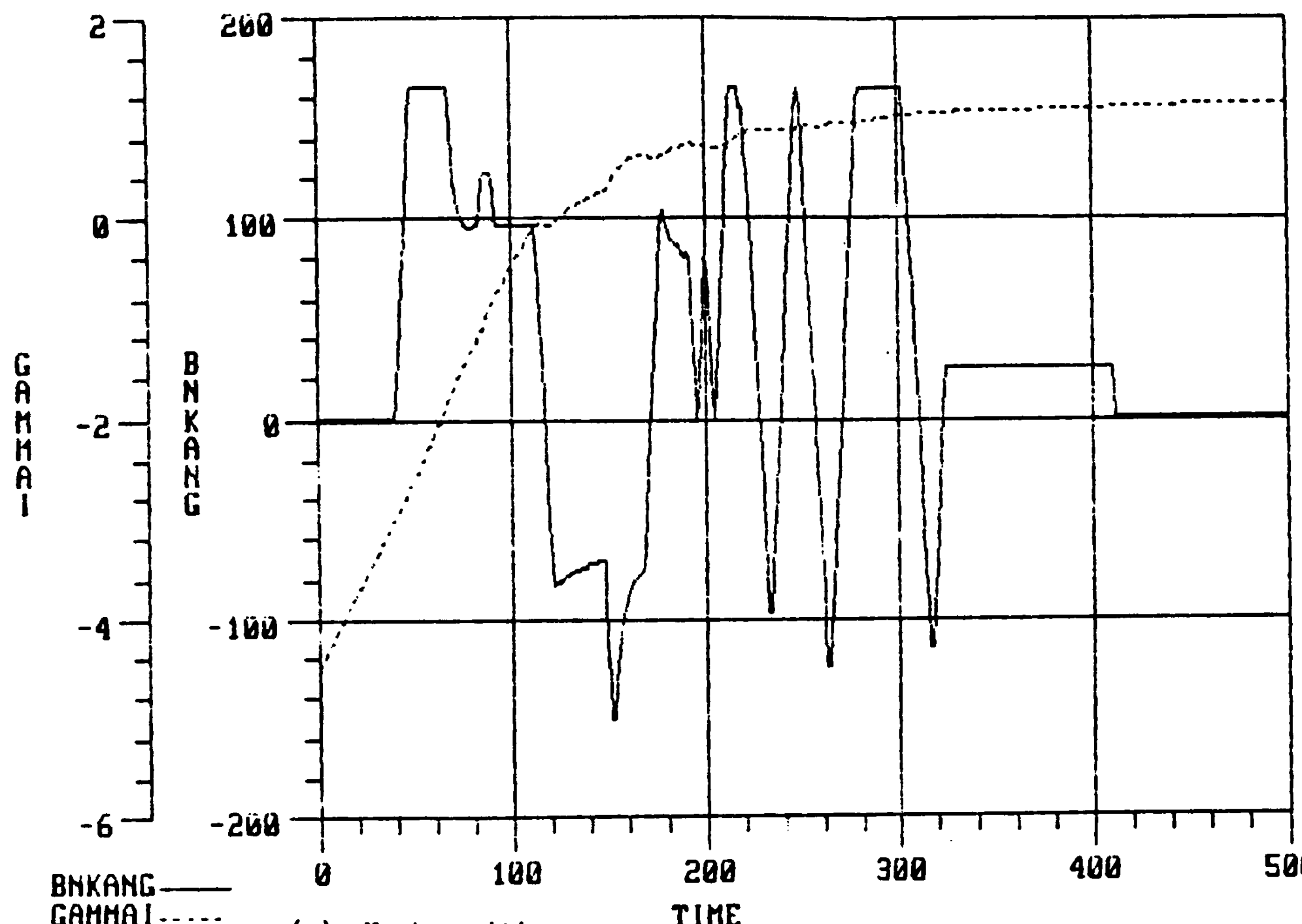
(b) Lockheed transition.

Figure 10. Continued.



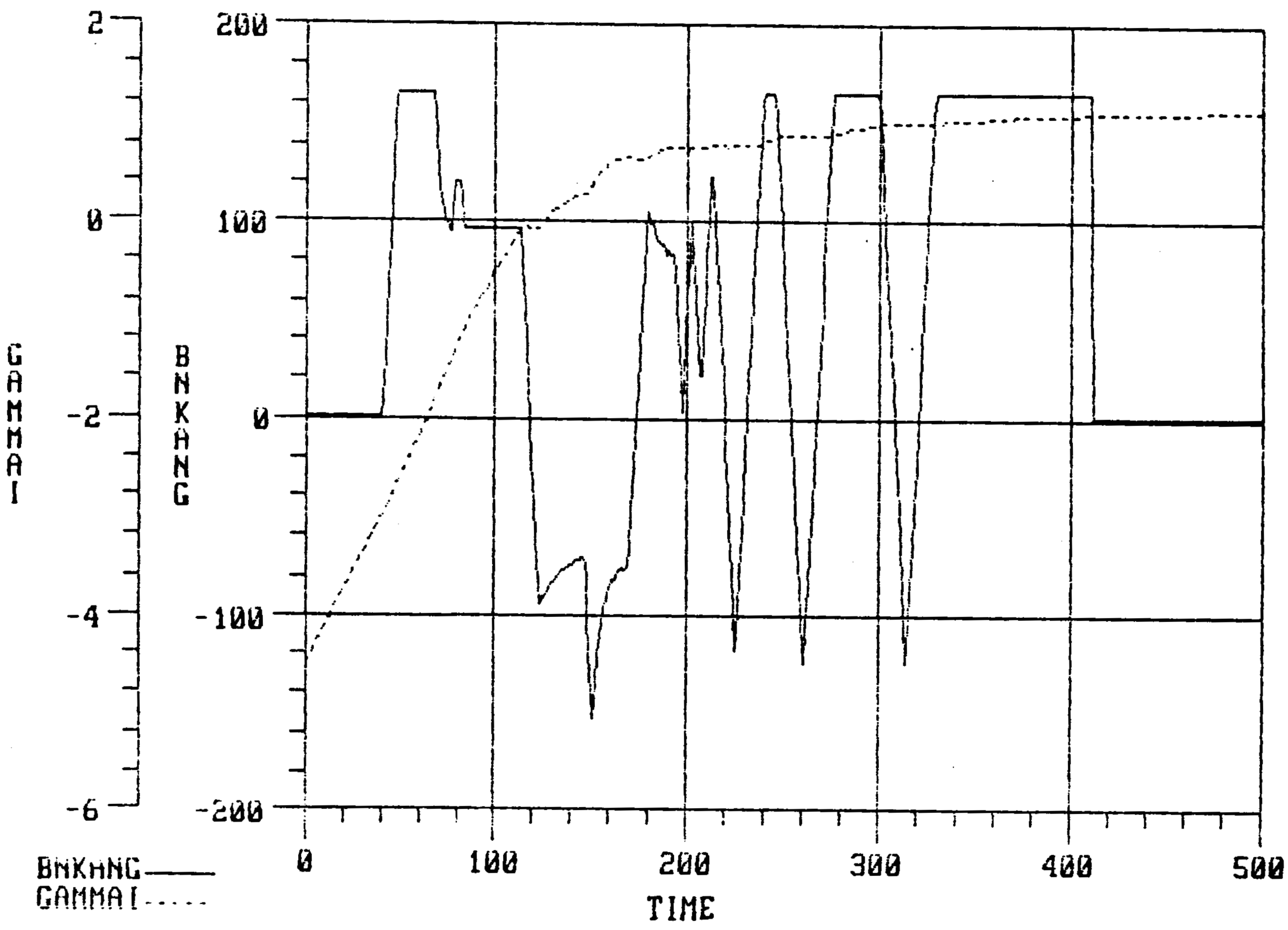
(c) Shock Reynolds transition.

Figure 10. Concluded.



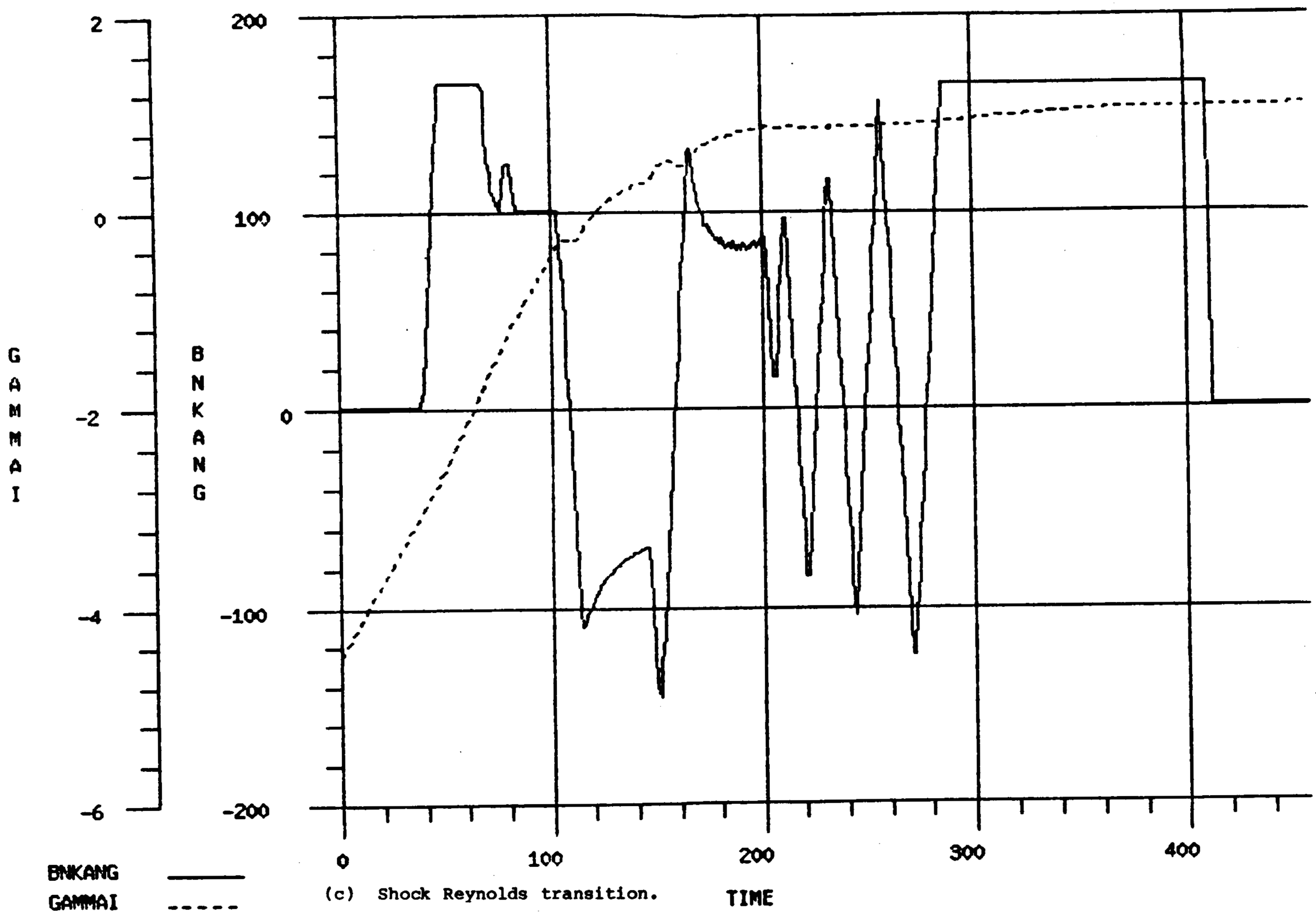
(a) No transition.

Figure 11. Bank angle time history for 25 degree out-in guidance modification with 20-second hold and 1976 atmosphere.



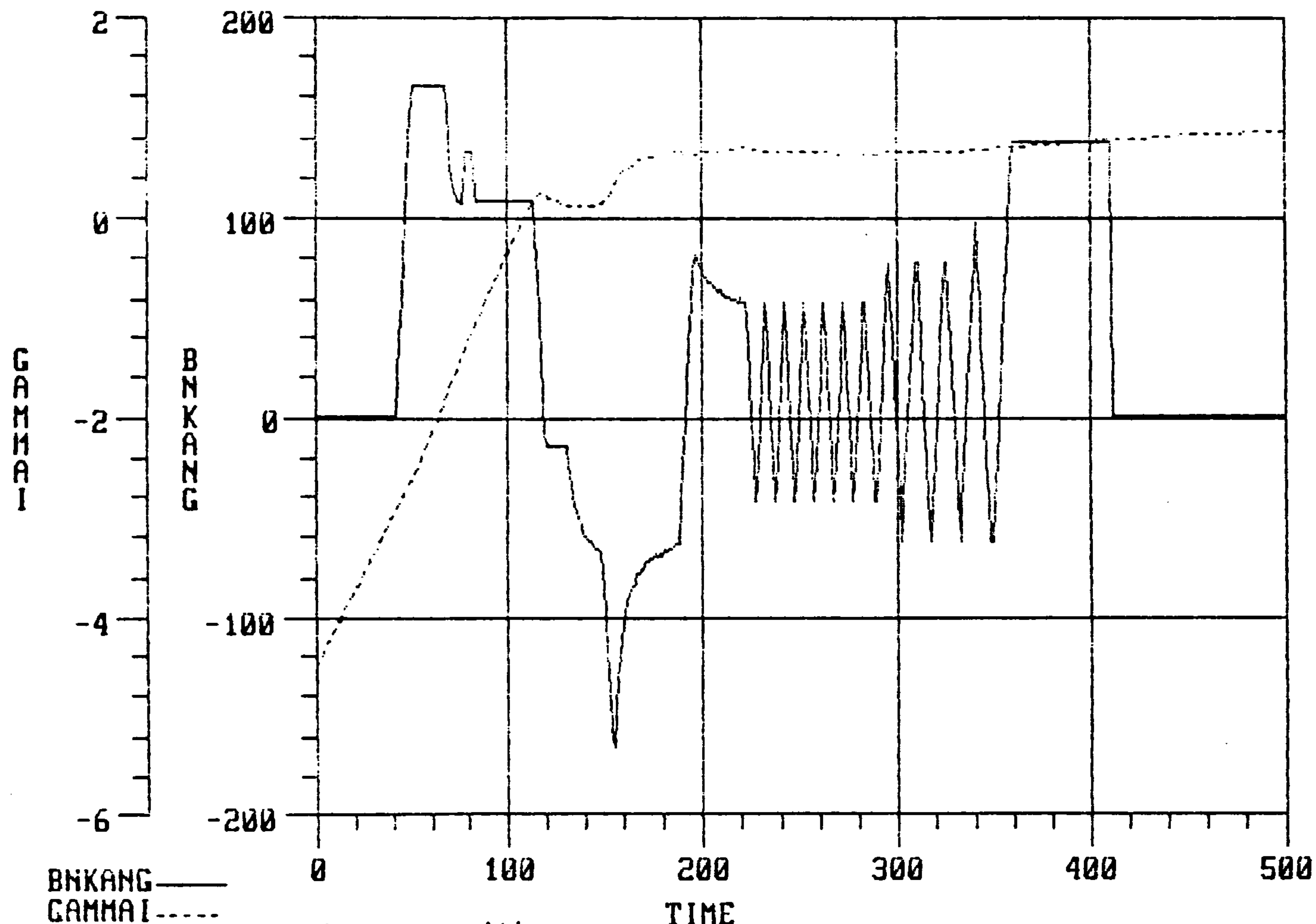
(b) Lockheed transition.

Figure 11. Continued.



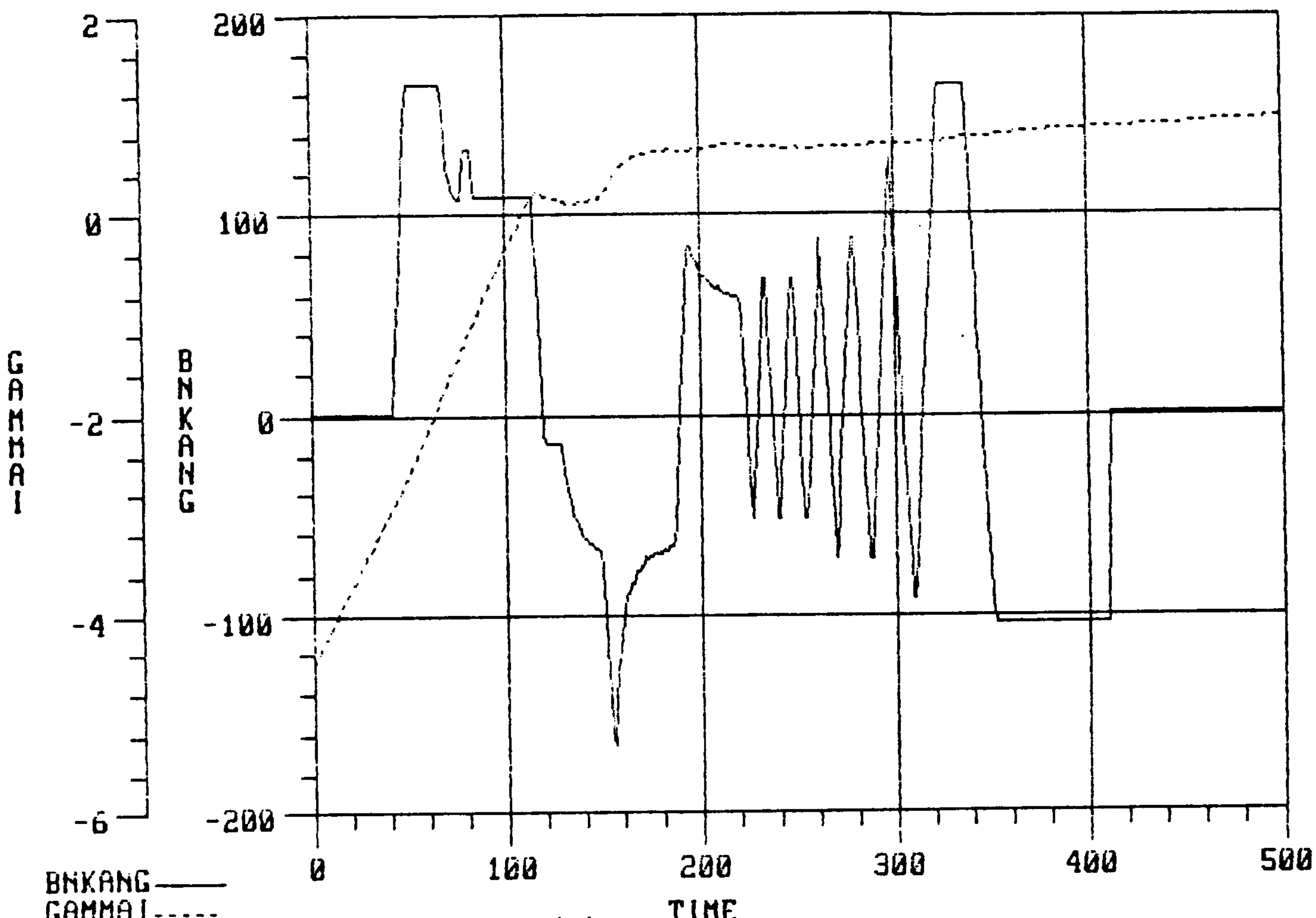
(c) Shock Reynolds transition.

Figure 11. Concluded.



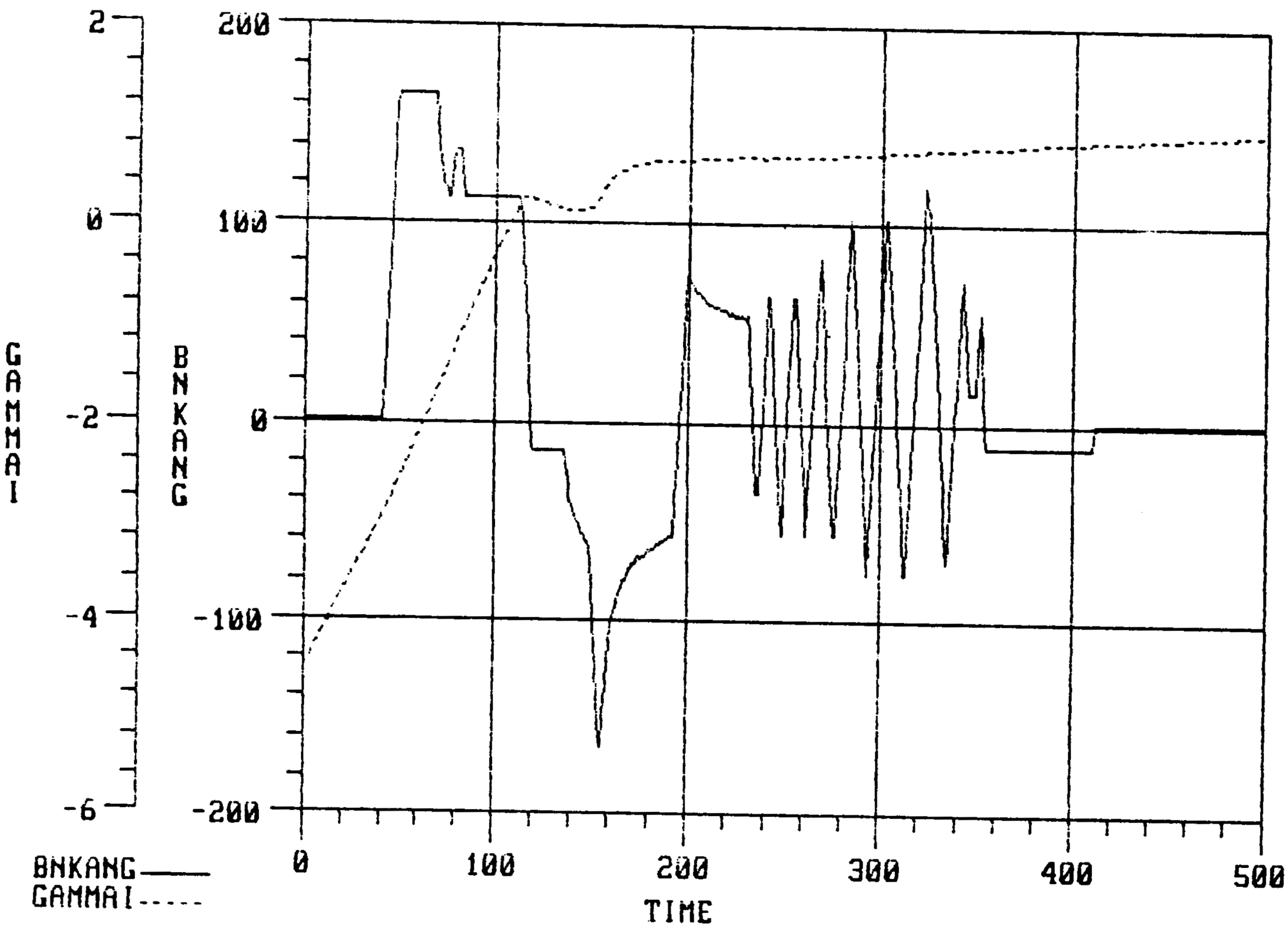
(a) No transition.

Figure 12. Bank angle time history for 25 degree out-in guidance modification with a 30-second hold and 1962 atmosphere.



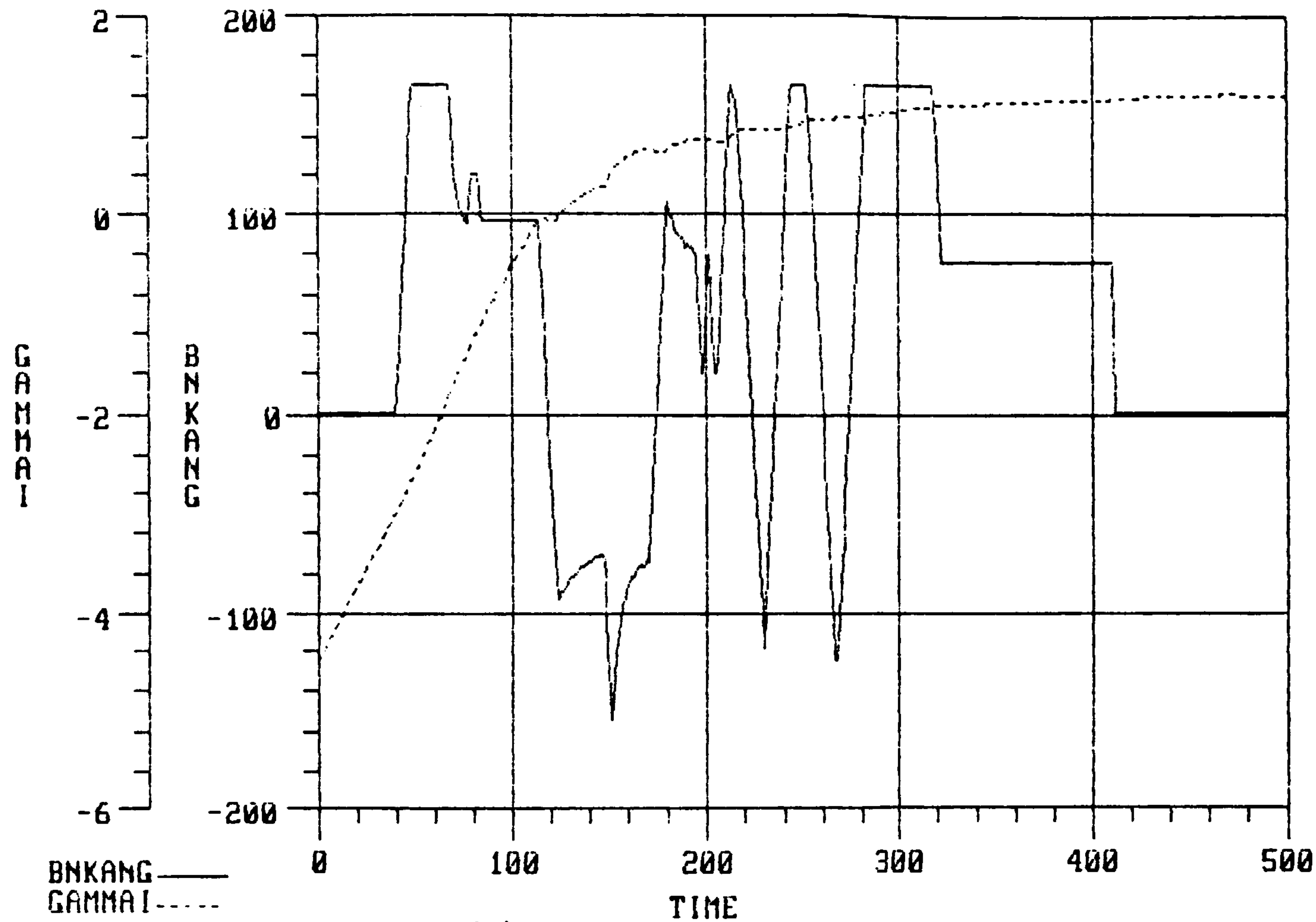
(b) Lockheed transition.

Figure 12. Continued.



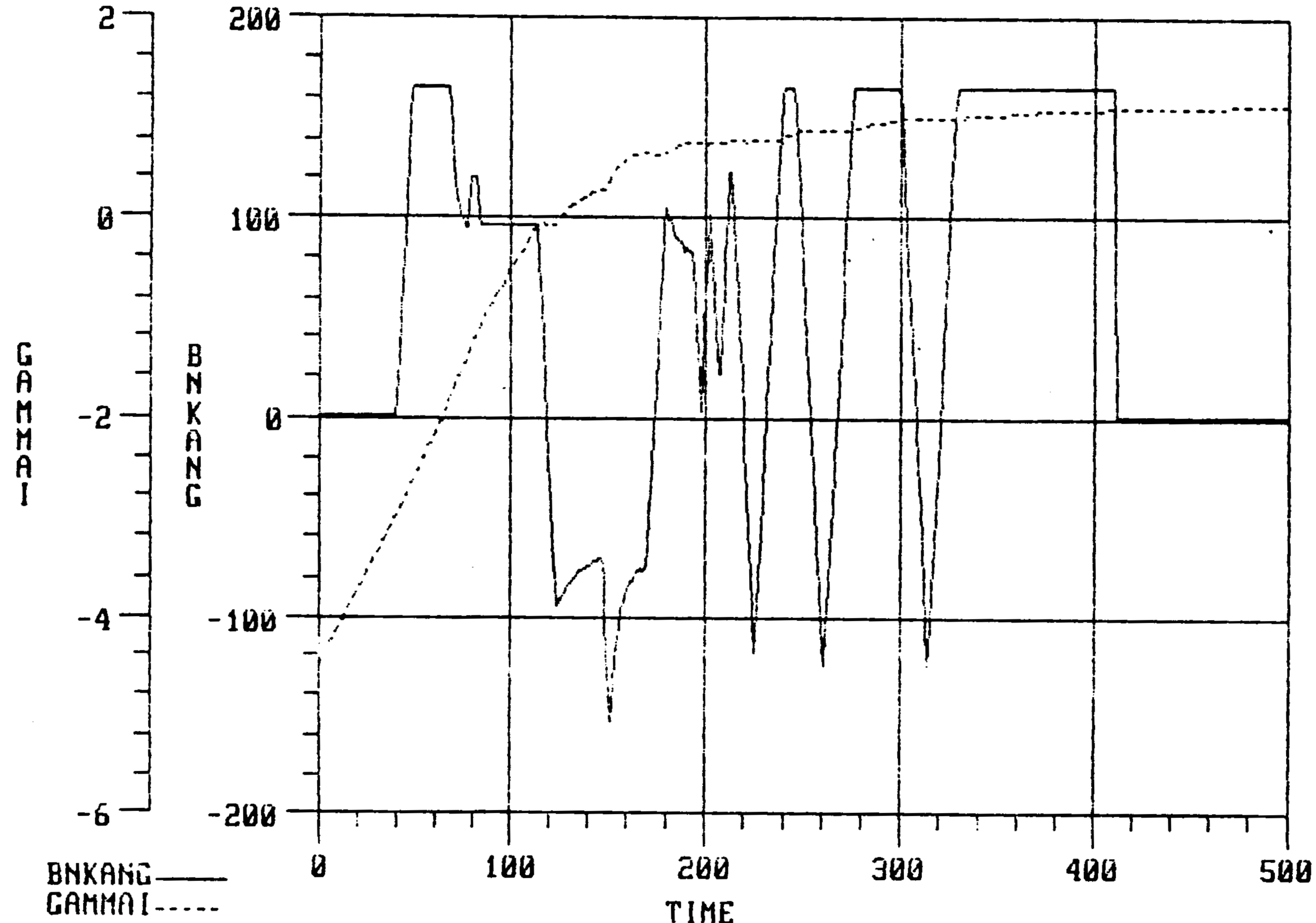
(c) Shock Reynolds transition.

Figure 12. Concluded.



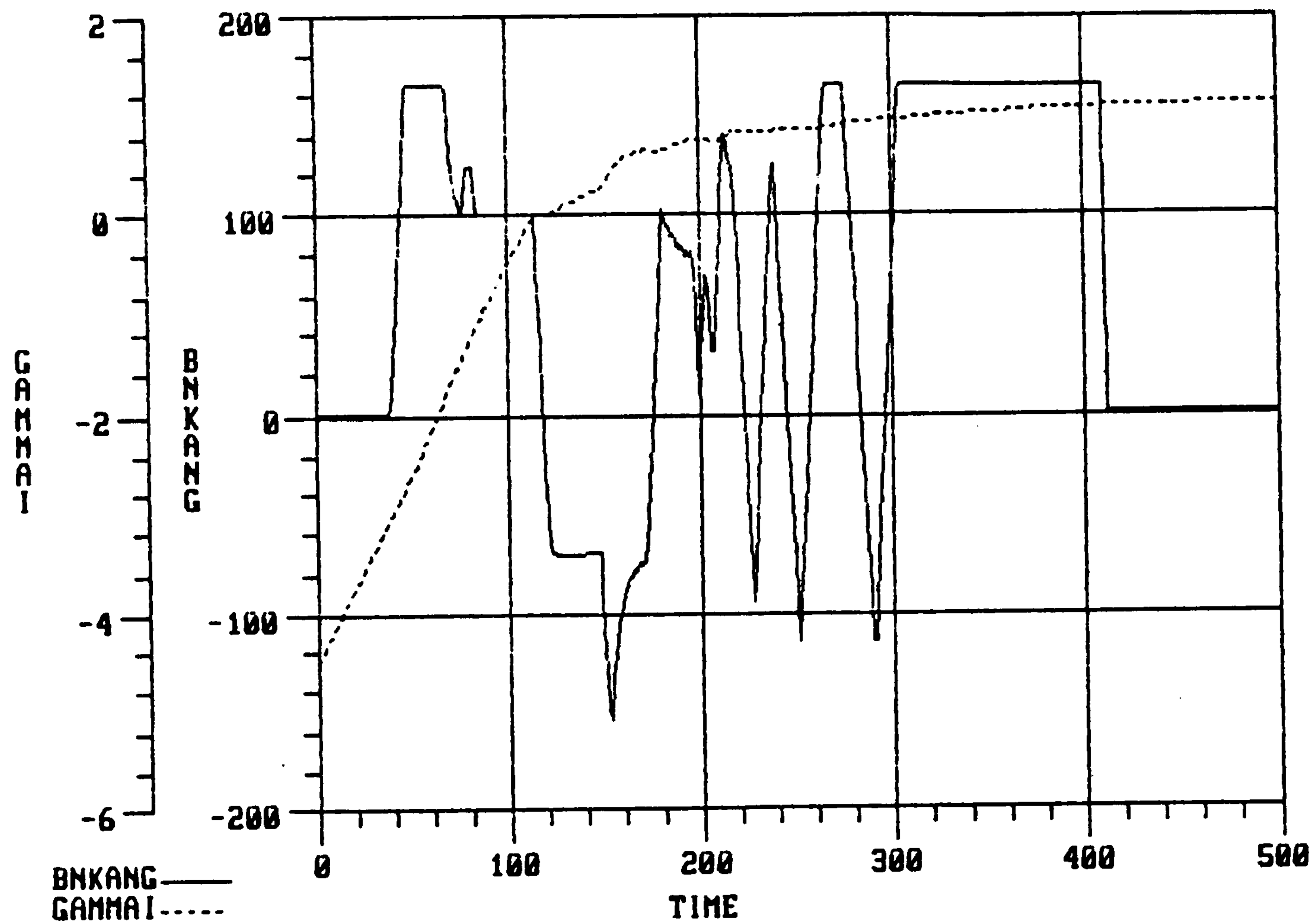
(a) No transition.

Figure 13. Bank angle time history for 25 degree out-in guidance modification with a 30-second hold and 1976 atmosphere.



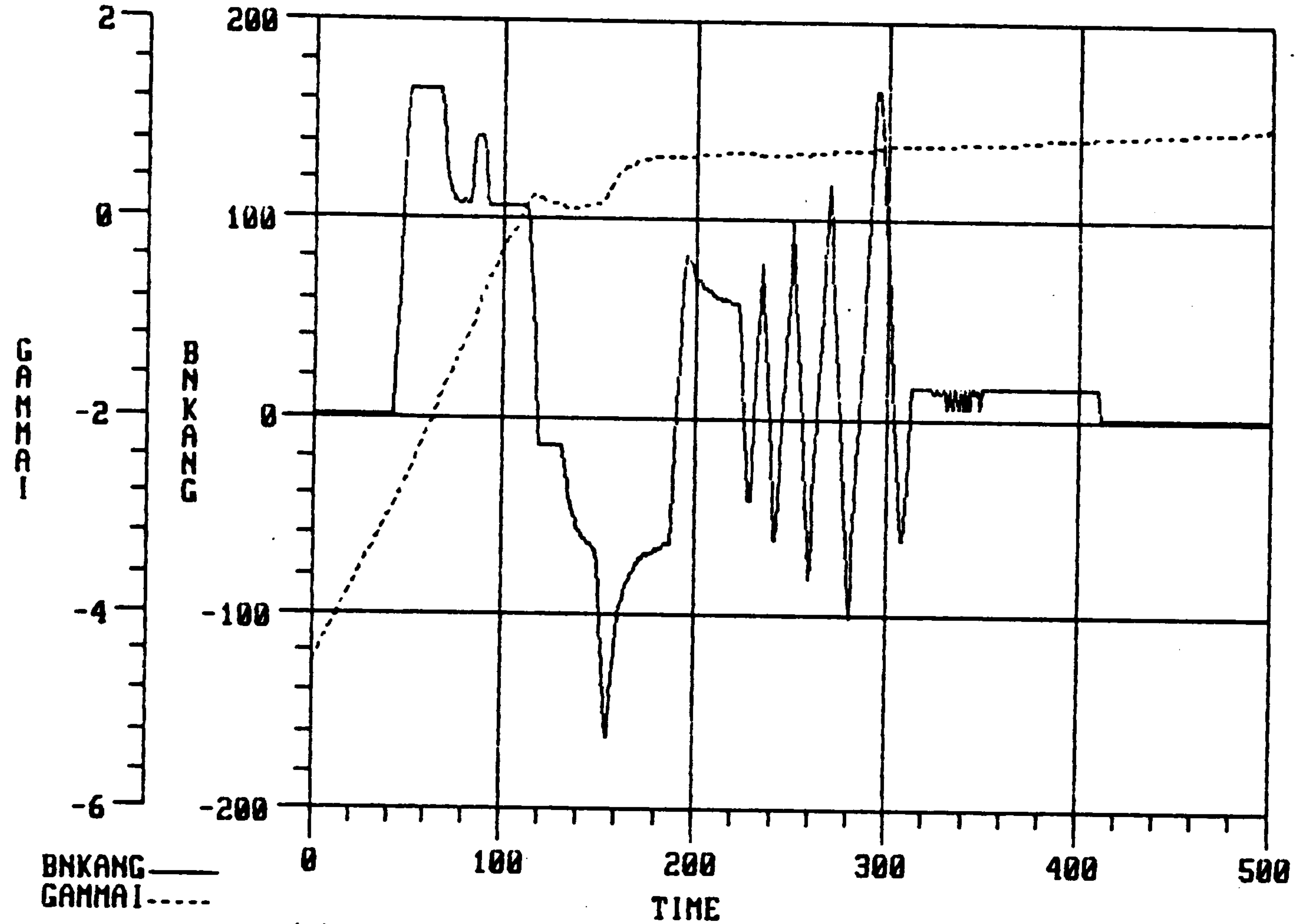
(b) Lockheed transition.

Figure 13. Continued.



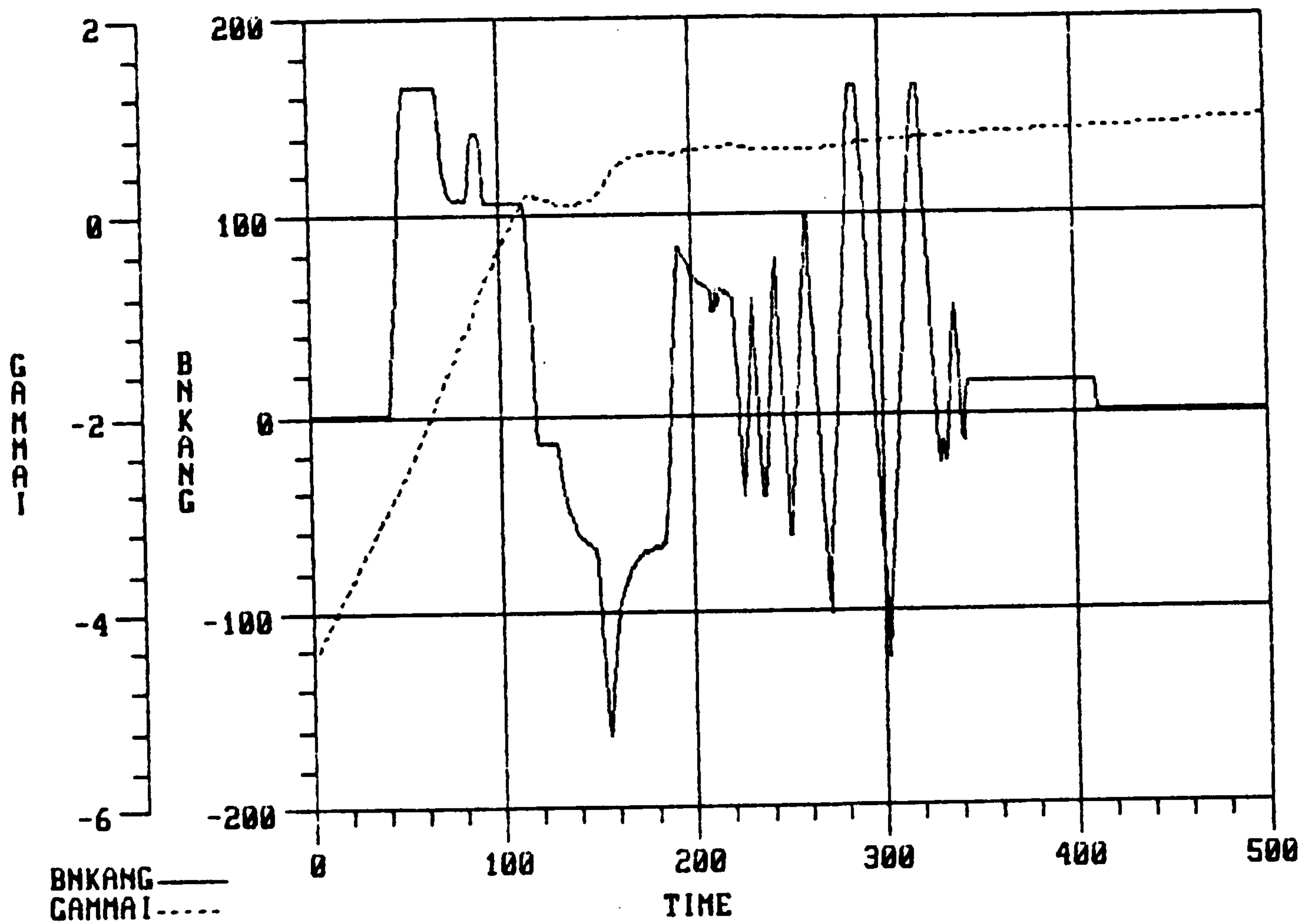
(c) Shock Reynolds transition.

Figure 13. Concluded.



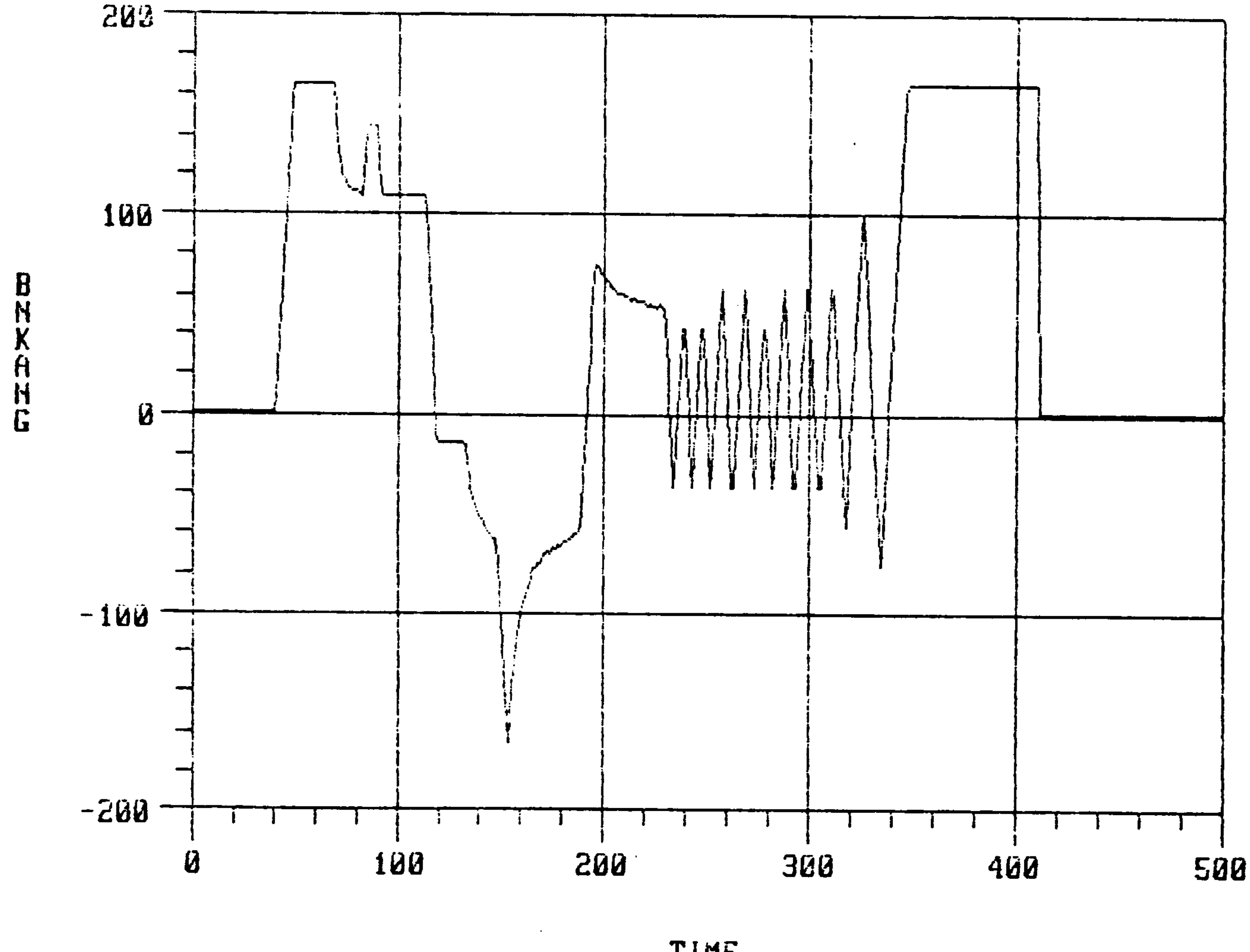
(a) No transition.

Figure 14. Bank angle time history for 35 degree out-in guidance modification with a 20-second hold and 1962 atmosphere.



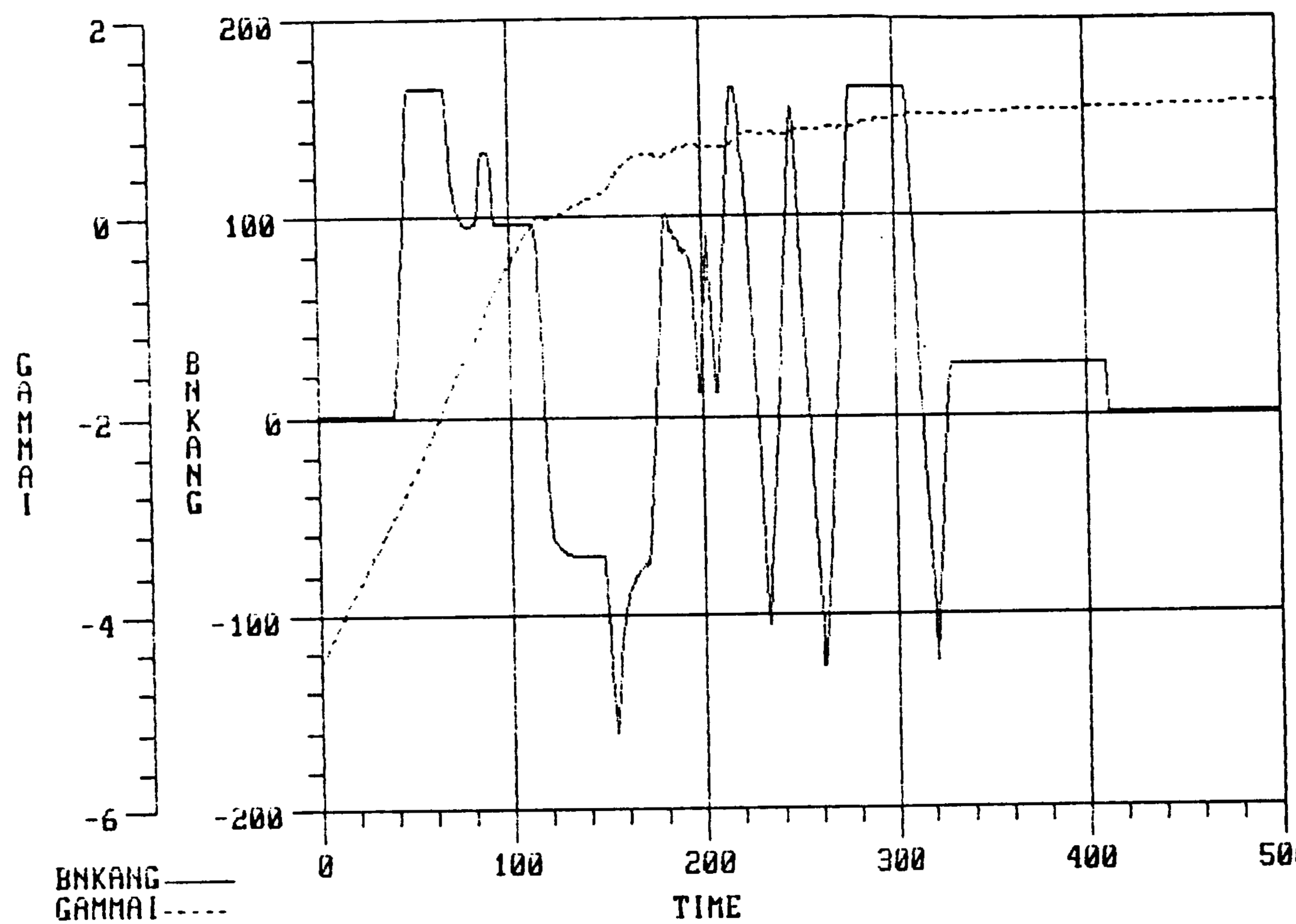
(b) Lockheed transition.

Figure 14. Continued.



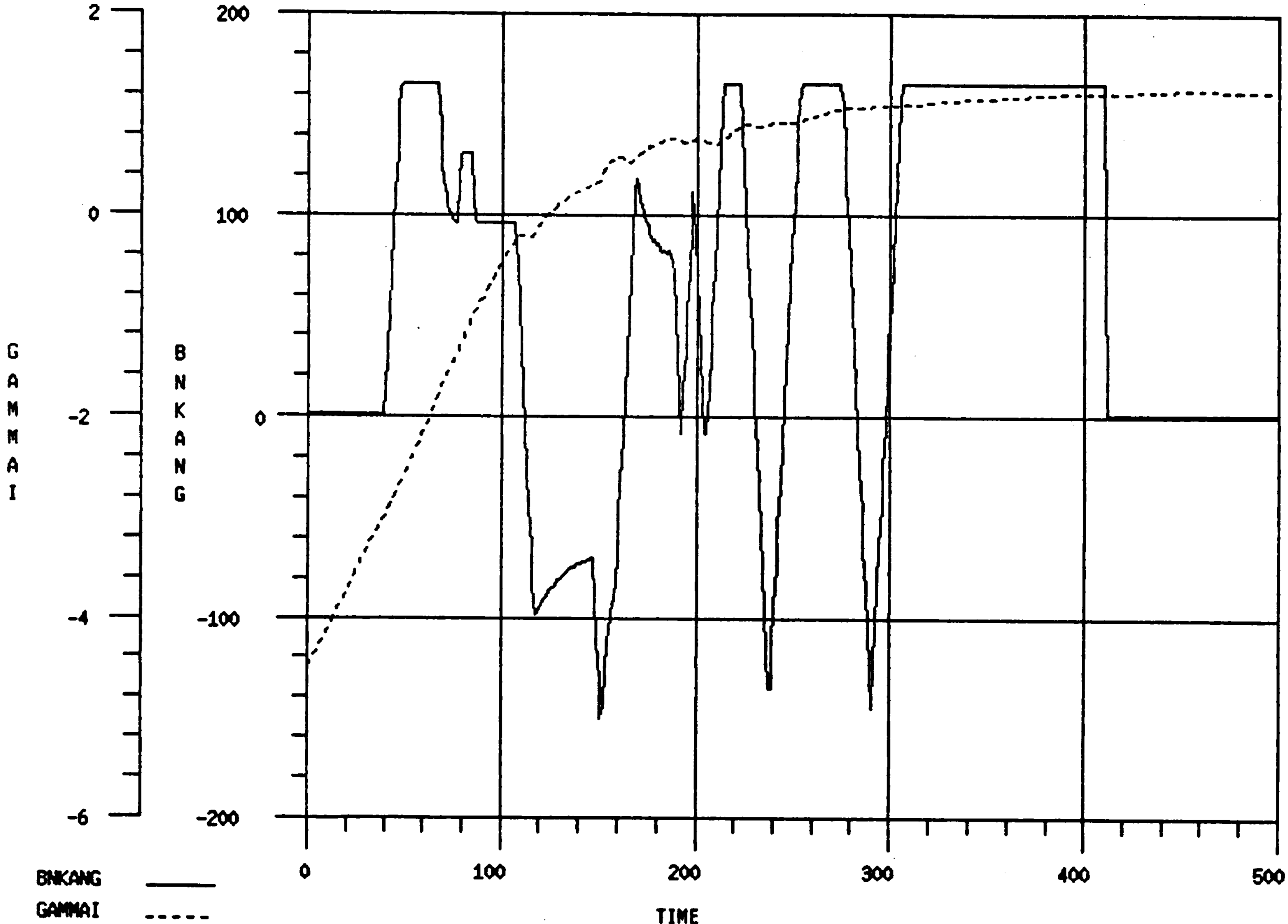
(c) Shock Reynolds transition.

Figure 14. Concluded.



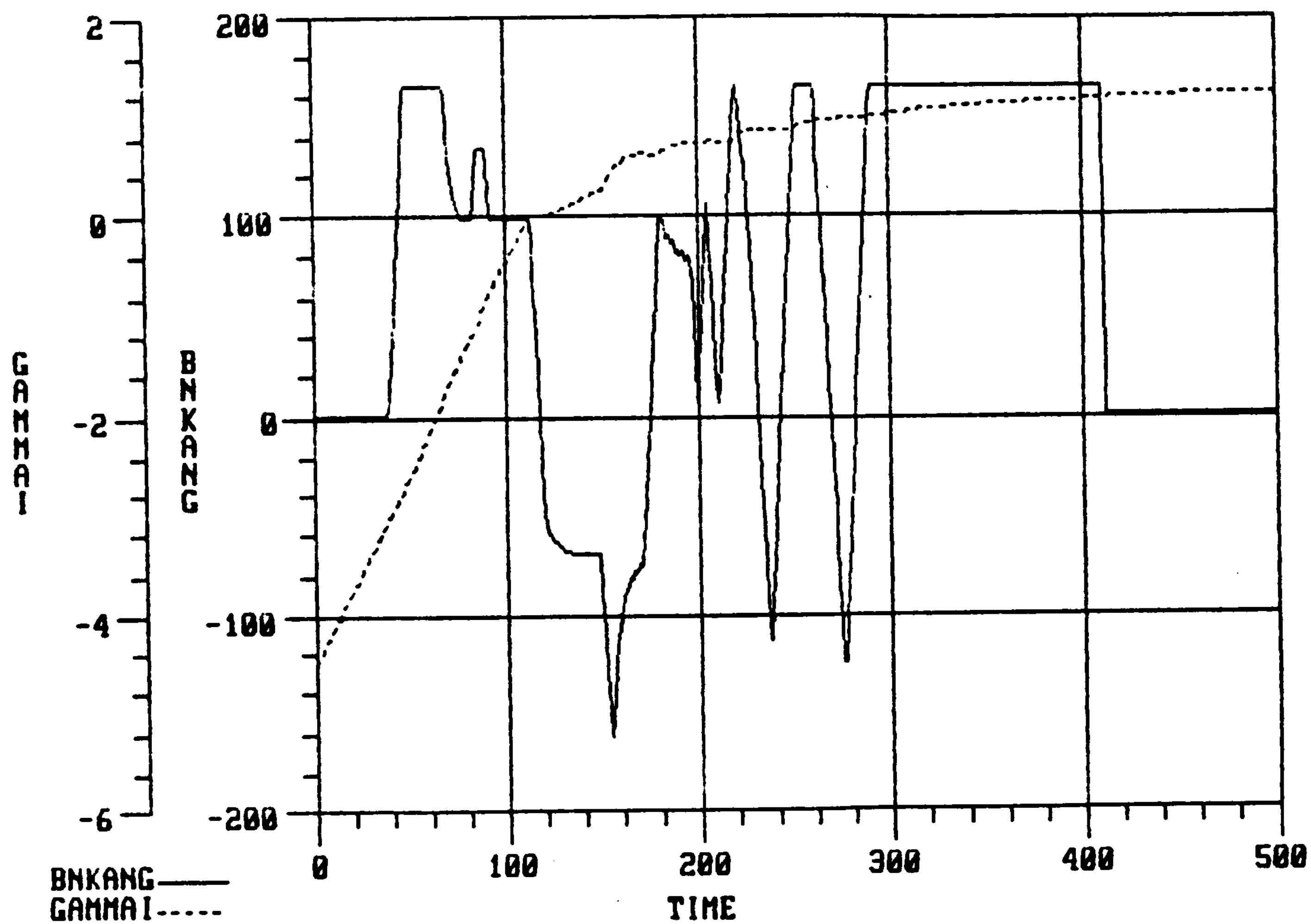
(a) No transition.

Figure 15. Bank angle time history for 35 degree out-in guidance modification with a 20-second hold and 1976 atmosphere.



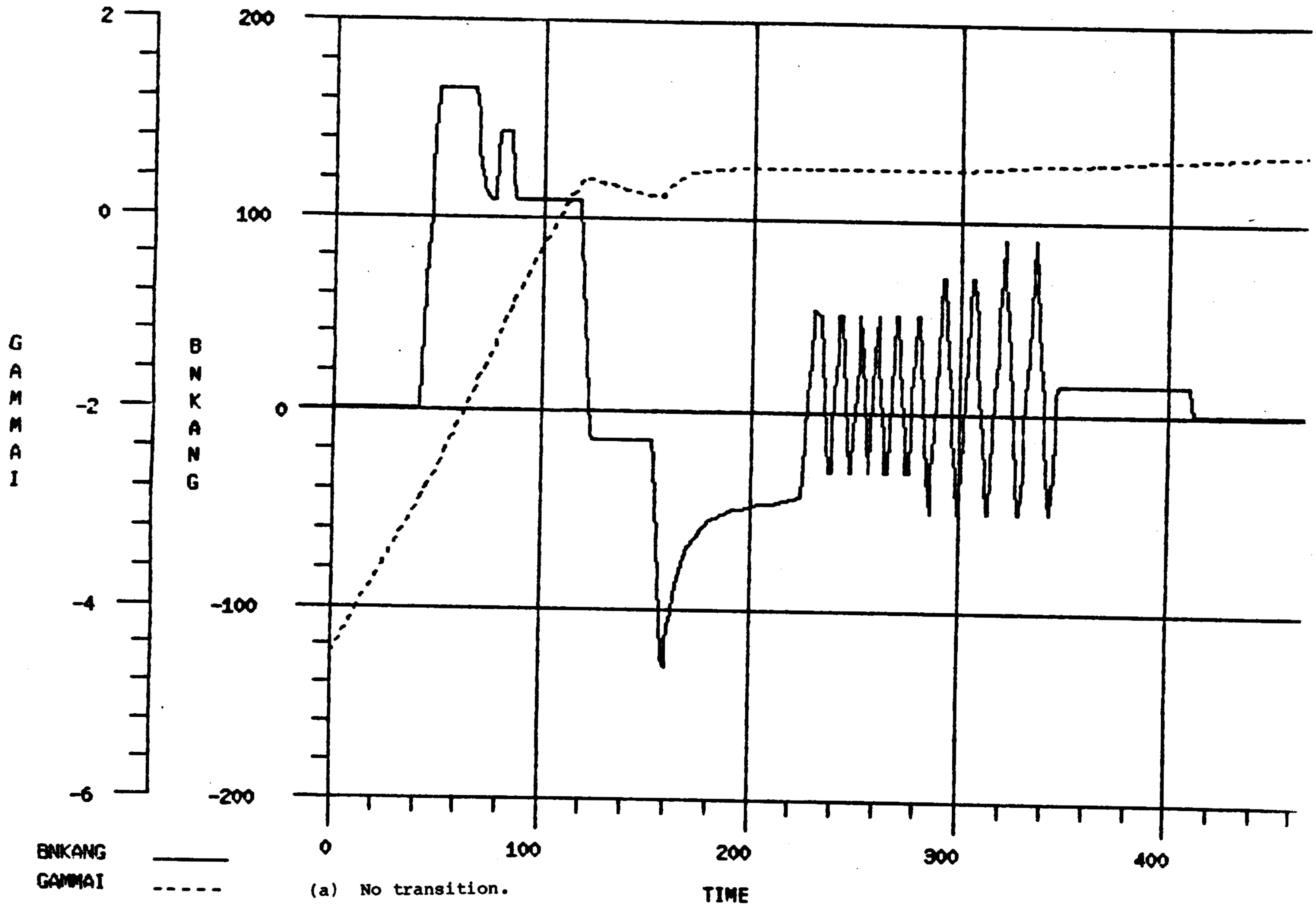
(b) Lockheed transition.

Figure 15. Continued.



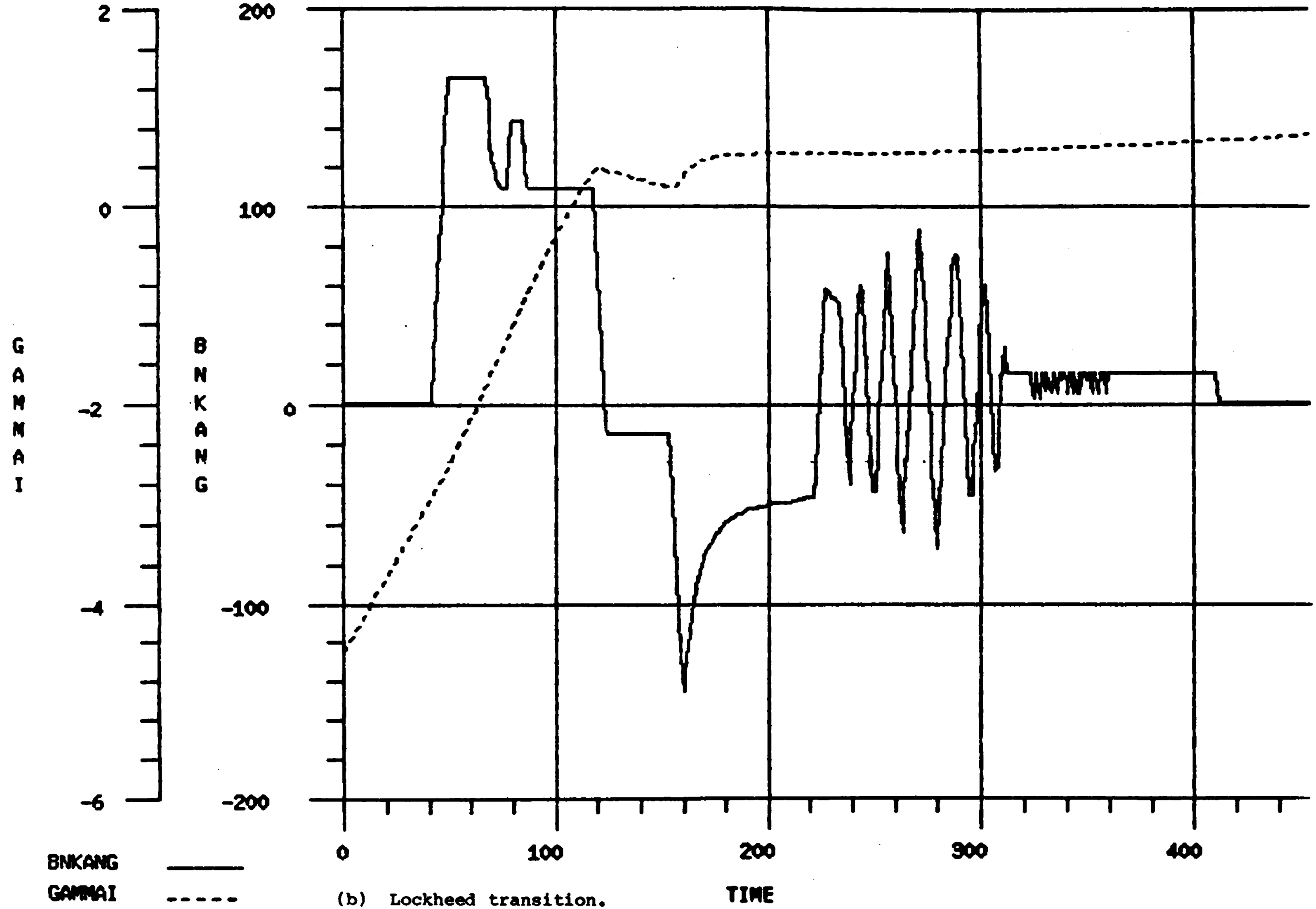
(c) Shock Reynolds transition.

Figure 15. Concluded.



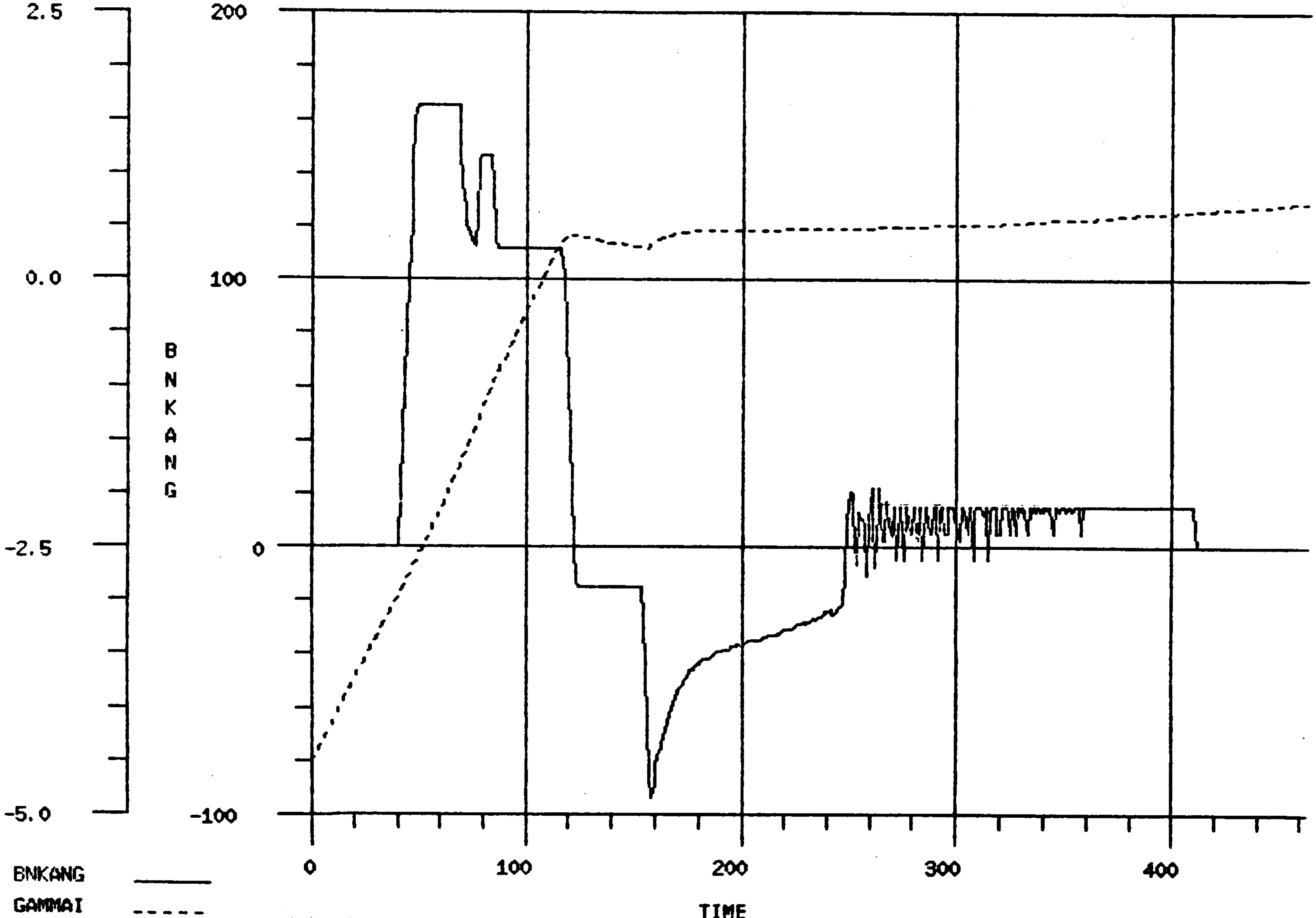
(a) No transition.

Figure 16. Bank angle time history for 35 degree out-in guidance modification with a 30-second hold and 1962 atmosphere.



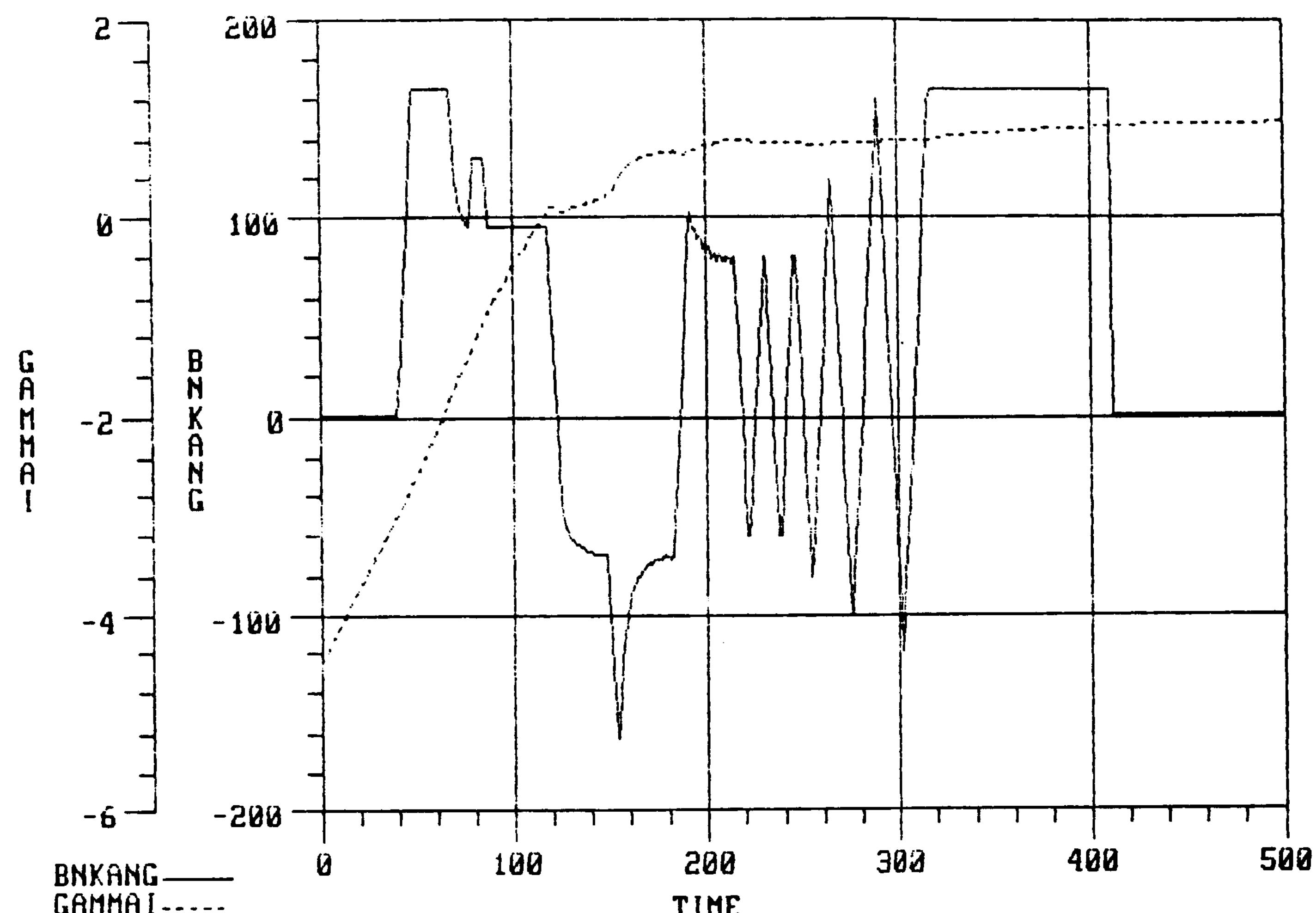
(b) Lockheed transition.

Figure 16. Continued.



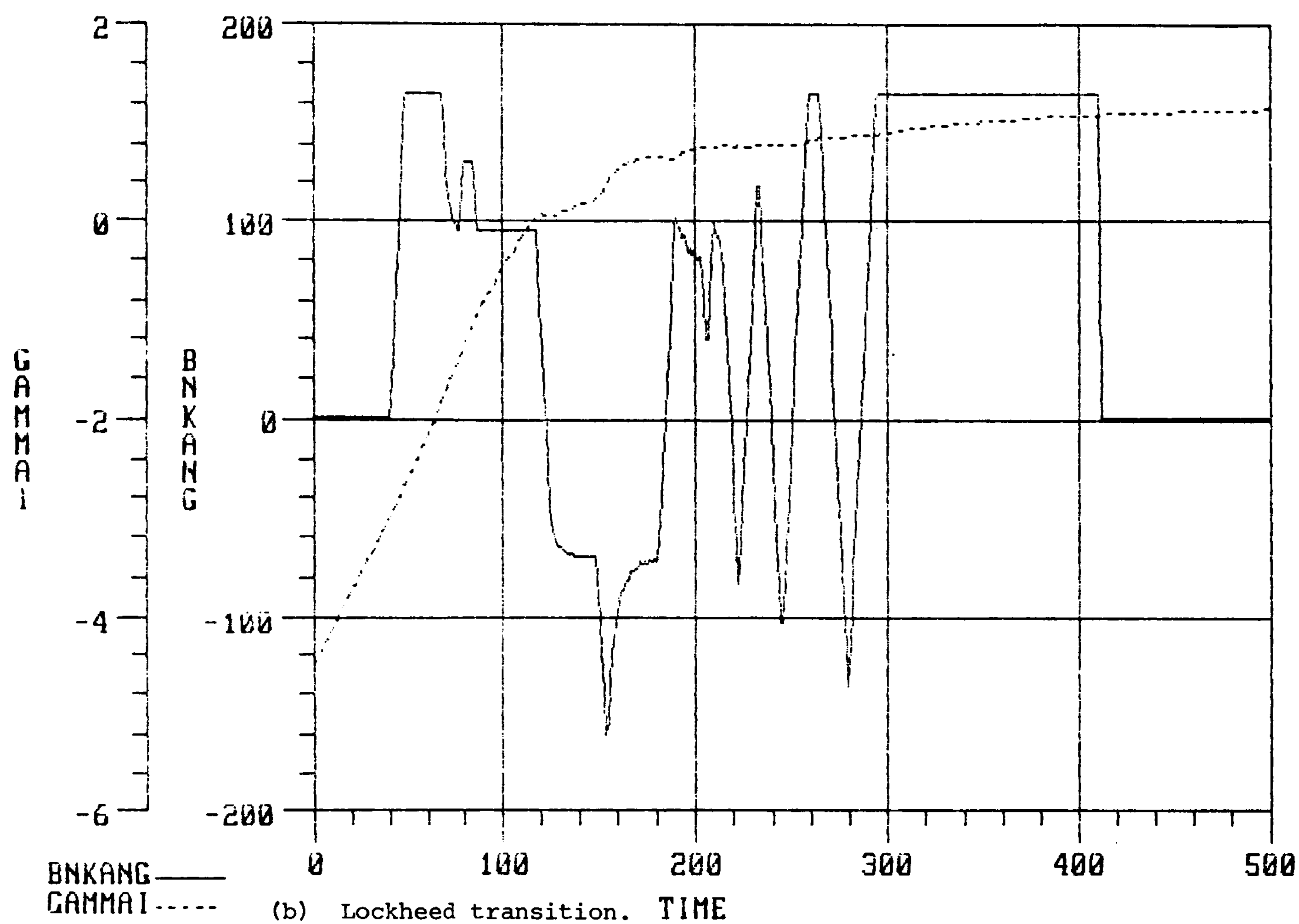
(c) Shock Reynolds transition.

Figure 16. Concluded.



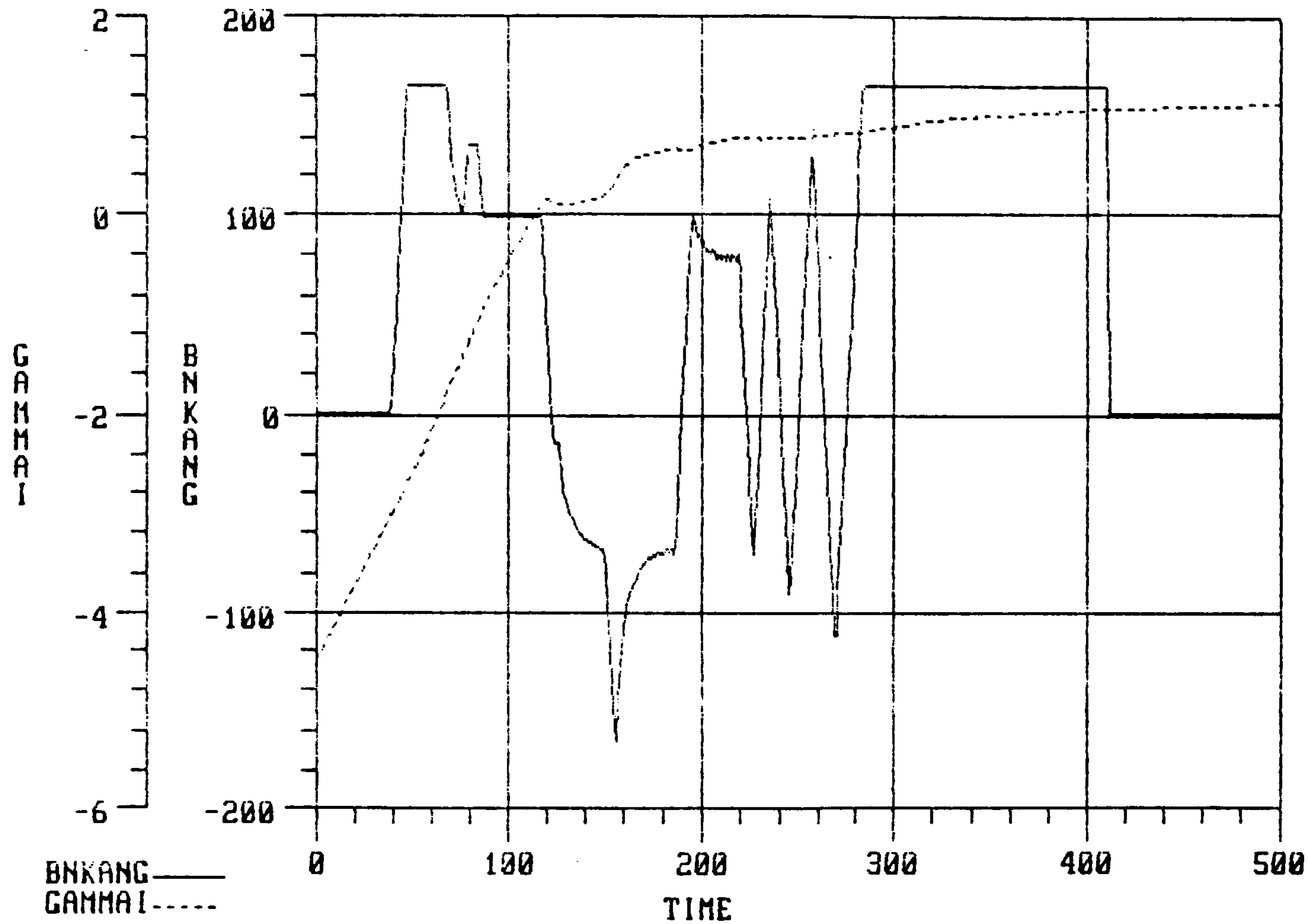
(a) No transition.

Figure 17. Bank angle time history for 36 degree out-in guidance modification with a 30-second hold and 1976 atmosphere.



(b) Lockheed transition.

Figure 17. Continued.



(c) Shock Reynolds transition.

Figure 17. Concluded.

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Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100556		

4. Title and Subtitle	5. Report Date
Aeroassist Flight Experiment Guidance "Quiet Time"	February 1988
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Scott A. Striepe and William T. Suit	
	10. Work Unit No.
	506-46-21-01
9. Performing Organization Name and Address	11. Contract or Grant No.
NASA Langley Research Center Hampton, VA 23665-5225	
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Technical Memorandum
National Aeronautics and Space Administration Washington, DC 20546-0001	14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The science experiments for the Aeroassist Flight Experiment (AFE) will be greatly enhanced by taking measurements with no Reaction Control System (RCS) contamination just before perigee. Methods of modifying the AFE guidance to accomplish this are discussed. Several methods that could give up to 30-seconds of "quiet time" were investigated and the results of these guidance modifications shown. A 20-second "quiet time" is definitely possible and a 30-second "quiet time" may be possible if the guidance can be inactive past perigee. Some questions that were raised during the guidance modification tests are listed; the most significant being the criterion for determining if the mission is threatened. A limited follow-on test program is outlined.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Spacecraft Guidance Aeroassist Spacecraft Maneuvers AFE Flight Project	Unclassified - Unlimited Subject Category 18

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of pages	22. Price
Unclassified	Unclassified	77	A05

NASA FORM 1626 OCT 86

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