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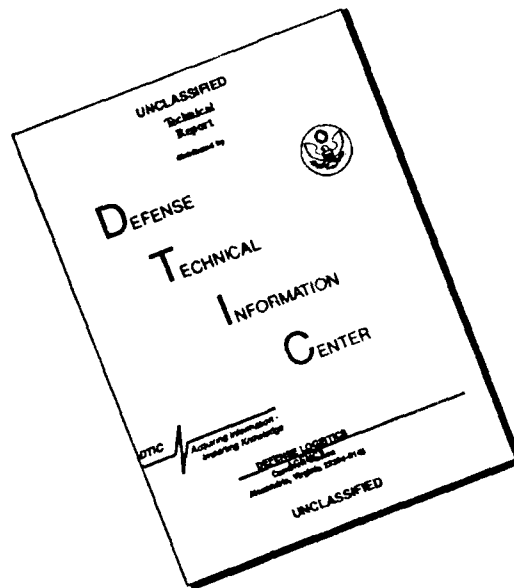
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SMALL BALLOON BALLISTIC TRACING AND BEHAVIOR ANOMALIES

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Abstract

A balloon tracking and meteorological data gathering system was developed for small free floating balloons. The evolution and test of this system and several small balloon flights are described. Balloons of different volumes were flown at several altitudes, varying durations and times of day. Position, pressure-altitude and temperature data from these flights were closely monitored. These data have been correlated with cloud cover, terrain, and diurnal changes. Data from the July 1990 flight series are described in the greatest detail.

1. History

During the summer for the past thirty years we have been flying large scientific balloons from eastern New Mexico westward toward the White Sands Missile Range. The penetration point of the Range airspace has always been of vital importance to the balloon-borne experiment. While the stratospheric easterly winds are very stable during this period, the statistical norm has often been an inadequate predictor. Various techniques have been tried to improve the predictability of the Range penetration point.

In 1972, in support of the VIKING project, we flew 7102 cubic meter balloons at 36.8 kilometers to provide a ballistic trace for the large balloons carrying the VIKING aero-shell and decelerator. These ballistic trace balloons were dubbed "Pathfinders", a title which has persisted to this day. These Pathfinders that were launched about 12 hours prior to the hot test produced results no better than the statistical norm. Tracking of these Pathfinders was accomplished using a GMD radiosonde unit, which tracked a VIZ radiosonde. No meteorological data were collected during float as these radiosondes were pressure commutated and no data switching occurred unless the balloon changed altitude.

In July 1986 Pathfinders were used again to provide a ballistic trace. The balloons were much smaller, 102 cubic meters, and floated at 23 kilometers. Ten flights were made. For this series the launch time was more precise. Five were launched at 2200 hours and five were launched at 0400 hours local time. Tracking was accomplished by using a modified GMD to receive a transmitted signal from a 1680 MHz Vaisala radiosonde. These radiosondes were electrically commutated. Continuous pressure and temperature were received for the entire flight sequence. The flight durations were

six hours and flight termination occurred by timer. Positions computed from the GMD antenna angles were recorded at 10-minute intervals. Data from these flights suggested a diurnal coupling, in that the trajectories for each launch time tended to group. Those flights launched at 2200 MDT tended to have trajectories slightly to the north of west, while the trajectories for those flights launched at 0400 MDT were south of west.

Much folklore has grown in the balloon community about the terrain and its effect on balloons floating in the stratosphere, particularly over the Sacramento Mountains between Roswell, NM and the White Sands Missile Range. The 1986 effort tended to suggest that perhaps diurnal variations were, in part, the cause of the deviations that had been observed in the past over this region.

2. Recent Pathfinders

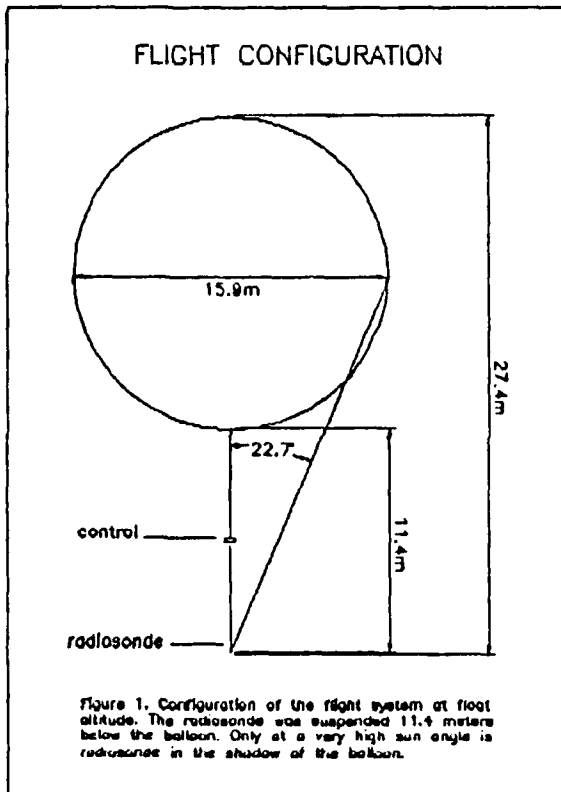
Two efforts, one in September 1989 and one in July 1990, were conducted to look at these anomalies in greater detail using a new tracking ground station we developed for this purpose. The four flight series in 1989 used balloons with volumes of 102, 1563 and 7102 cubic meters, and were flown at altitudes 16, 21, 30 and 37 km. The 37 km flight, discussed later, was aloft for eighteen hours.

The second effort, during July 1990, consisted of a series of small balloons, 1563 cubic meters, that were flown from Roswell, NM to the west side of the White Sands Missile Range, NM, which is located 185 kilometers west of Roswell. These flights were released over a seven-day period. Each flight was launched four hours earlier in time than on the preceding day. The releases were scheduled for 1200, 0800, 0400, 0000, 2000 and 1600 hours MDT. This schedule was followed as closely as weather permitted. The balloons used were manufactured by RAVEN Industries from 0.127 millimeter Astrofilm E. These 1563 cubic meter balloons will carry a 16 kilogram payload to an altitude of 30 kilometers. At this altitude the stratospheric winds, during July, produce an average westerly drift of 16 meters per second. The flight durations varied between four and six hours depending on weather and recovery conditions. Seven launches were made. Good data were collected on five flights. There was one balloon failure and one launch failure.



3. Flight System

The flight system consisted of a control board which automatically controlled flight termination and ballast pour functions, a Vaisala RS-80N (OMEGA) radiosonde, a flashing strobe warning light, (aneroid "off" at 18.3 km), a 138.125 MHz command receiver, a tone decoder, and a 3.7 meter diameter flat circular parachute. Each flight system weighed from 20 to 45 kg. Generally 10% pourable ballast was carried on each flight. The RS-80N Vaisala radiosonde was suspended 5.5 meters, the length of the OMEGA antenna, below the flight package. The 3.7 meter parachute (extended length 5.5 meters) was flown in-line above the flight package. The overall length of the flight train was 11.4 meters. The flight configuration is shown in Figure 1.



Flight termination would occur either after a preset time or when the balloon descended to an altitude of 18.3 km. The ballasting system was set so that the ballast pour "arm" occurred 256 minutes after the package was turned "on". Once armed, a three-percent ballast pour would occur when the balloon descended below 27.4 km (The ballast floor). The nominal float altitude was 30.5 km. After the pour was made, 32 minutes later a second pour was made if the balloon had not ascended above 27.4 km. For the last three flights the ballast floor was disabled. Pours were

made at 32 minute intervals after "arm" regardless of the altitude. We disarmed the ballast floor to eliminate data degradation caused by changes in altitude.

4. Ground Station

The Ground Station, not named after the developer and author, has a Communitronics 403 MHz receiver with a bandwidth of 1000 KHz, a TRACOR OMEGA navigator, an AT 286 computer with a color monitor, a dot matrix parallel printer, a Vaisala PPI1 meteorological data processor, an interface signal conditioner box, a 403 MHz omni receive antenna, an OMEGA receive antenna, and an operating software package for data processing and display. These components are housed in transportable cases that interconnect into a work station. Setup and breakdown time is about one hour. A LORAN Micrologic navigator was added after this flight series. Power requirements are 110 Volts 15 amp service.

5. Methodology

All but one of the flight systems were small and light enough to be hand launched. Launches were made either at Holloman AFB, NM or from the Roswell Industrial Air Center just south of the town of Roswell, NM. Command, control and data acquisition functions were located in building 850, Holloman AFB, NM. The 403 MHz data signal was acquired immediately for the Holloman AFB launches and were at about 9 km for those flights launched from Roswell, NM. Position and meteorological data were received and stored in an ASCII format. The flight timers were set for the maximum anticipated time the flight would be within acceptable acquisition and command range. Once set, the timer settings could not be changed in flight. The flights could be terminated at any time by command.

In the data center the incoming signal was split with the OMEGA tracking data going to an OMEGA Navigator and the meteorological data going to a Vaisala PPI1 data processor. Position data were recorded at one minute intervals, while the meteorological data were recorded at 1.5 second intervals. Position and meteorological data were integrated into ASCII data files via a software program developed by Optimetrics, Inc. The position data were also displayed graphically to provide a visual realtime trace of the balloon trajectory.

For daytime terminations a surveillance aircraft was used to spot the payload and guide the ground recovery crew to the site. For nighttime terminations a search was made the following day to locate the payload. These attempts were not very successful. Two of the seven payloads were recovered.

Availability Dates	
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6. Flight Synopses

The trajectories flown in the September 1989 and July 1990 series are shown below in Table 1 and Table 2

TABLE 1

HOLLOMAN AFB, NM
September 1989

BLN SZ m ³	ALT km	DUR hrs	DIST FROM STA km
272	21	8	120
1563	30	7	217
272	16	3.5	144
7102	37	18	222

Table 1. Listed above are the a balloon size, float altitude, flight duration and termination distance from the launch point for the September 1989 PATHFINDER flights.

TABLE 2

ROSWELL AIR INDUSTRIAL CENTER
July 1991

BLN SZ m ³	ALT km	DURATION hrs	DIST FROM STA nm
1563	29	4.6	95
1563	29	3.9	90
1563	30	5.4	135
1563	29	5.6	125
1563	29	4.4	120

Table 2. Listed above are the balloon size, float altitude, flight duration and termination distance from the launch point for the July 1990 flights.

7. 1989 Flights

The most significant event of the 1989 series was the 36.6 kilometer flight launched on Sept 30 at 1842 MDT. The launch time was chosen so that the balloon would reach float altitude after balloon sunset which greatly reduced the need for ballast to maintain float altitude during the night. Since this was the time of minimum stratospheric winds a flight duration of at least eighteen hours was expected and the flight timers were set for eighteen hours. The flight trajectory is shown in Figure 2. The change in direction at 75 km west of the launch point occurred at balloon sunrise when the balloon ascended from 32 to 37 km. At termination the the balloon was about 185 km from the launch point.

The "y" (north-south) component was plotted against time as shown in Figure 3. A general north drift was experienced for most of the flight, except the turning to the south at 1600 UCT. This turning is

the south at 1600 UCT. This turning is consistent with the data from the 1986 Pathfinder flights.

Another interesting aspect of this flight was the comparison of two tracking techniques. A VIZ radiosonde was flown and tracked with a GMD. In addition, a Vaisala OMEGA radiosonde was flown and tracked with the Omega tracking station we had developed. A distance comparison is shown in Figure 4. Relative Omega positions tracked very well, however, deviations from the GMD positions varied from 22 to 3 kilometers. The orientation error (not shown) between the GMD and OMEGA tracking systems was very stable. The mean error was a -50 degrees from north (360 degrees). The best agreement in the distance error occurred at around 1200 UCT.

H89-21 FLIGHT TRAJECTORY
HOLLOMAN AFB, NM SEPT 30, 1989

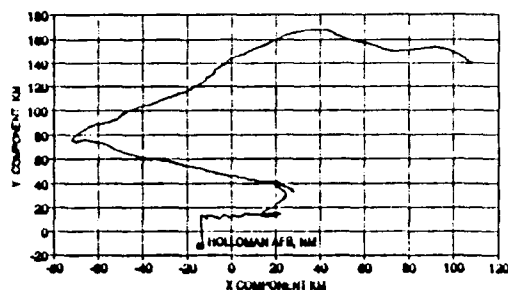


Figure 2. Flight H89-21 was launched from Holloman AFB, NM at 1842 MDT. The balloon stayed within 200 kilometers of the launch site for 18 hours.

H89-21 Y COMPONENT VS TIME
HOLLOMAN AFB, NM SEPT 30, 1989

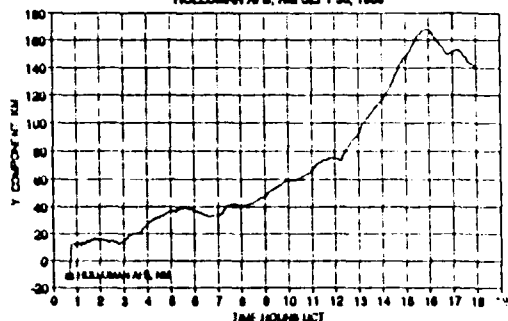


Figure 3. Flight H89-21 was launched from Holloman AFB, NM at 1842 MDT. Note the sharp change in the trajectory at 1600 UCT.

The balloon reached its nighttime float altitude, 36 km, about one hour after balloon sunset. The float and temperature profiles were nominal. After achieving float, the balloon was quite stable, descending very slowly through the night. The ballast floor, 32 kilometers, was reached just prior to balloon sunrise. Therefore, it is uncertain whether the

initial rise in altitude shown in Figure 5 is due to sunrise or a ballast pour. In either case warming occurred immediately and the temperature remained elevated and stable for the remainder of the flight. At this point the flight drift changes from westerly to easterly. Although not as strong as on subsequent daytime flights, increased temperature fluctuations were noted.

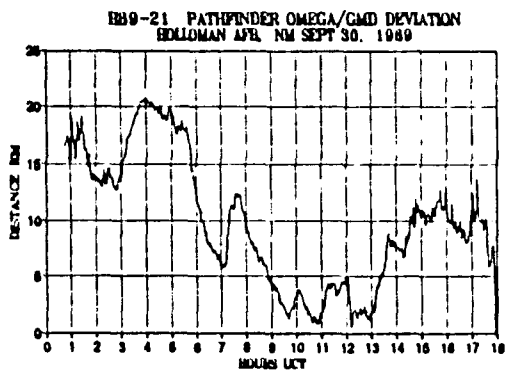


Figure 4. Flight H89-21 was launched from Holloman AFB, NM at 1842 MDT. Note the differences in the deviations for different times of the day.

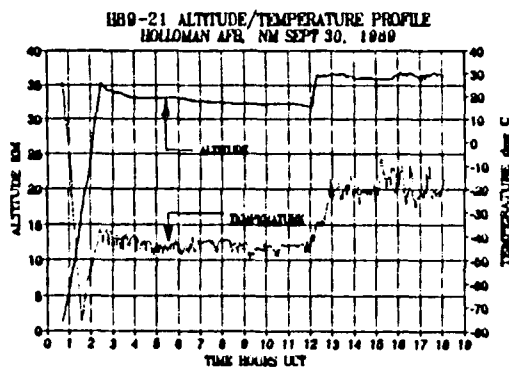


Figure 5. Flight H89-21 was launched from Holloman AFB, NM at 1842 MDT. The sharp rise in altitude and temperature began just prior to balloon sunrise.

8. 1990 Flights

The trajectories, altitude and temperature profiles for the five good data flights launched from Roswell, NM in July of 1990 are shown in Figures 6 through 14.

The first flight, H90-08, was launched at 1226 MDT on July 28, 1990. Three significant features were noted on this flight. First, just after reaching float altitude, 29 km, the balloon began a moderate descent at about one meter per second which continued at this rate to the termination altitude, 21 km. Second, the trajectory backed from a westerly to a west southwesterly heading. The point of change was 75 km west of the launch site.

The time was 1500 MDT. Third, after reaching float there were 20 degree temperature spikes. The ambient temperature was a -43 degree C. The slow constant descent would have provided some ventilation for the thermistor and damped the boundary layer effects, therefore, a more stable temperature curve would be expected. The trajectory, Y component versus time and temperature/altitude profiles are shown in Figures 6, 7 and 8. The cloud cover along the trajectory was generally thin cirrus clouds, except for a heavy cumulus formation over the Sacramento Mountains.

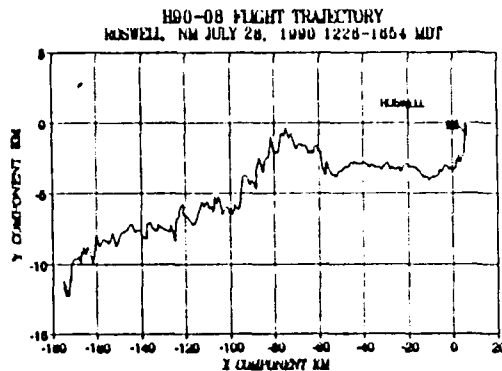


Figure 6. Flight H90-08 was launched from Roswell, NM at 1226 MDT. Note the change in trajectory at -80 kilometers.

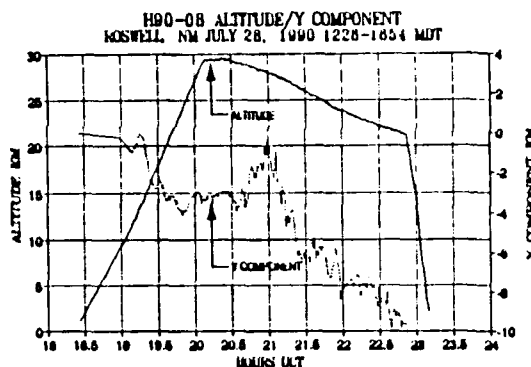


Figure 7. Flight H90-08 was launched from Roswell, NM at 1226 MDT. Note the change in trajectory at 2100 UCT.

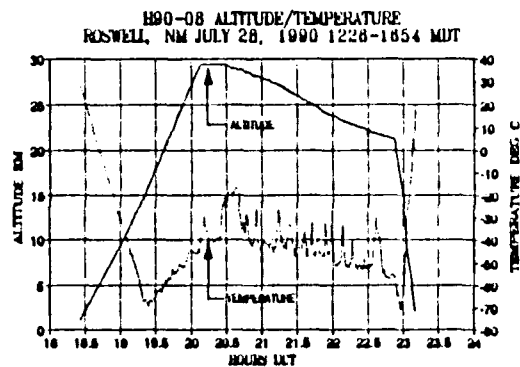


Figure 8. Flight H90-08 was launched from Roswell, NM at 1226 MDT. Note the large temperature deviations throughout the float period.

The second flight, H90-09, was launched at 0909 MDT on July 29, 1990. It reached float altitude, 29.4 kilometers, at 1100 MDT, floated through solar noon and was terminated at 1300 MDT. Unlike the previous flight there were fluctuation in

the trajectory but no significant backing or veering. A strong thermal spike occurred just after the balloon entered float. These data are shown in Figures 9, 10 and 11. From the balloon's geometry and sun angle it is estimated that the thermistor was in the balloon's shadow from 1145 MDT until termination. During this period the temperatures appeared more stable and slightly cooler. The cloud cover along the trajectory was thin broken cirrus clouds. Ballast pours occurred at 1222 and 1254 MDT.

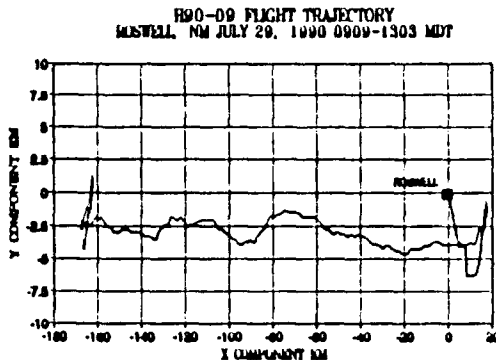


Figure 9. Flight H90-09 was launched from Roswell, NM at 0909 MDT.

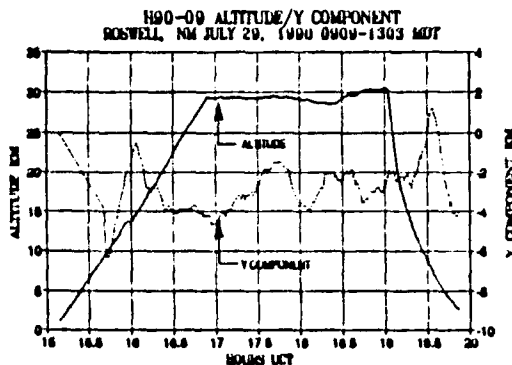


Figure 10. Flight H90-09 was launched from Roswell, NM at 0909 MDT. No significant changes were noted in the Y (north-south) component.

The third flight, H90-10, was launched at 0414 MDT on July 30, 1990. Sunrise occurred during ascent at 21 kilometers. Backing to the west southwest heading was noted in the trajectory, however, the point of change was further west, 120 kilometers west of the launch site. The time was 0800 MDT. At 0900 the drift to the southwest changed back to the more normal westerly drift. In the early portion of the float period the temperatures were relatively stable. The occurrence of thermal spikes began about 0730 MDT and continued sporadically until

termination. See Figures 12, 13, and 14. Ballast drops were made at 0750, 0822 and 0854. The cloud cover was scattered to thin broken cirrus clouds.

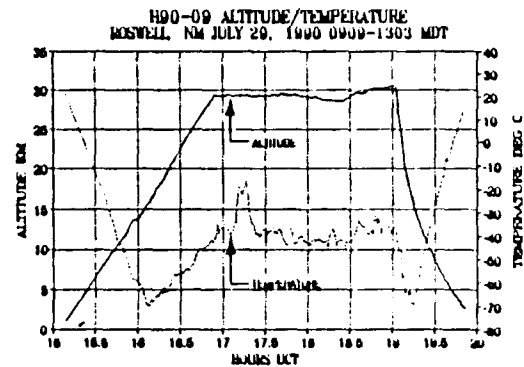


Figure 11. Flight H90-09 was launched from Roswell, NM at 0909 MDT. Note the strong temperature deviations just after the balloon entered float.

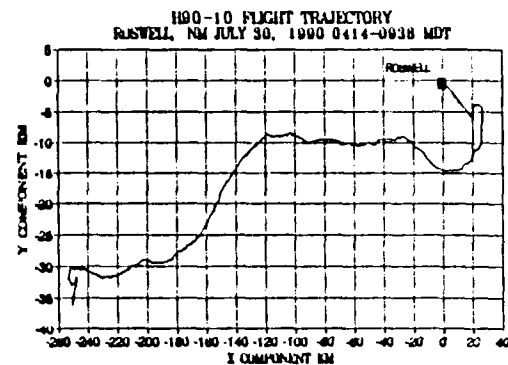


Figure 12. Flight H90-10 was launched from Roswell, NM at 0414 MDT. Note the strong backing in the trajectory at -120 kilometers.

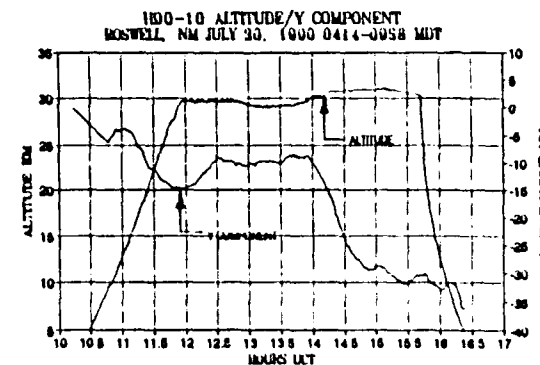


Figure 13. Flight H90-10 was launched from Roswell, NM at 0414 MDT. Note the change in trajectory at 1400 UCT.

The fourth flight, H90-11 was launched at 2358 MDT on July 31, 1990. Climbout and float were in darkness. As in the previous flights there was a backing of the trajectory. The point of change for this flight was 150 kilometers west of the launch site and the time was 0400 MDT. The

temperature was relatively stable and near ambient -45 degree C. There were slight spikes in the negative direction, consistent with downwash from the cooler radiative temperatures of the balloon. The graphical descriptions for this flight are shown in Figures 15, 16 and 17. Ballast drops were made at 0928, 1000 and 1032 MDT. This flight overflew a thin broken cirrus cloud layer.

The fifth and final flight of the series, H90-13, was launched at 1916 MDT on August 2, 1990. Balloon sunset occurred during ascent at 23 kilometers. Immediately after reaching float a descent of 2.5 meters per second was established and continued until the first ballast drop at 2308 MDT. A second drop was made at 2340 MDT. The trajectory in this case veered slightly instead of backing as in the previous flights at 140 kilometers west of the launch point. The time was 2230 MDT. The temperature trace for this flight was the most stable of all the flights. There were no significant deviations. The trace tracked the float descent and ascent of the balloon very well. These data are shown in Figures 18, 19, and 20. Cloud cover for this flight was a layer of thin broken cirrus clouds.

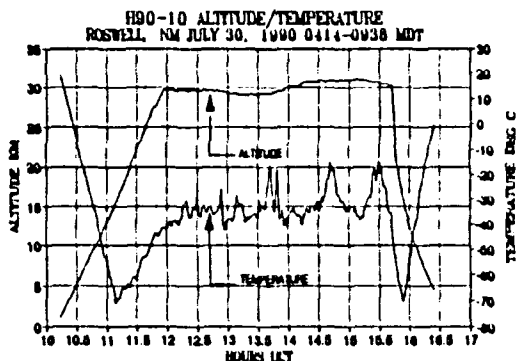


Figure 14. Flight H90-10 was launched from Roswell, NM at 0414 MDT. Note the strong temperature fluctuations after balloon sunrise.

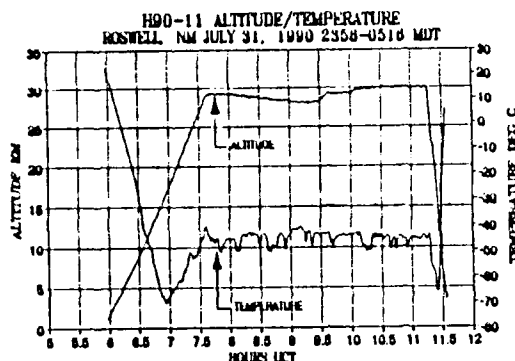


Figure 17. Flight H90-11 was launched from Roswell, NM at 2358 MDT. Note the negative temperature fluctuations.

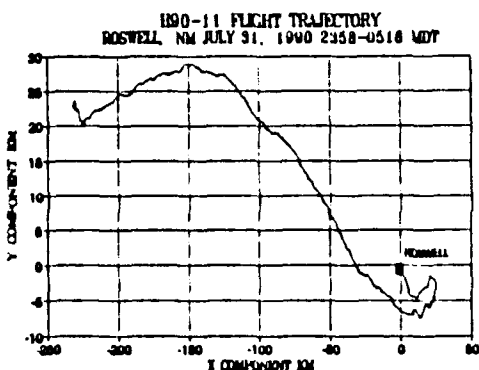


Figure 15. Flight H90-11 was launched from Roswell, NM at 2358 MDT. Note the backing in trajectory at -160 kilometers.

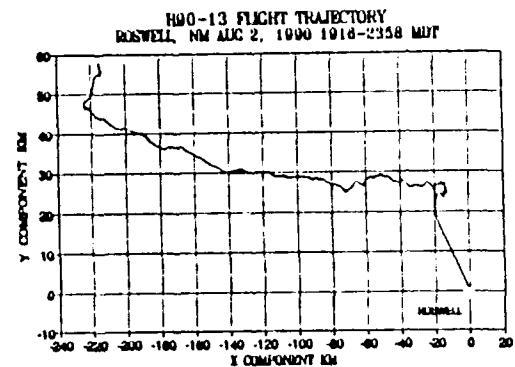


Figure 18. Flight H90-13 was launched from Roswell, NM at 1916 MDT. Note the veering in trajectory at -169 kilometers.

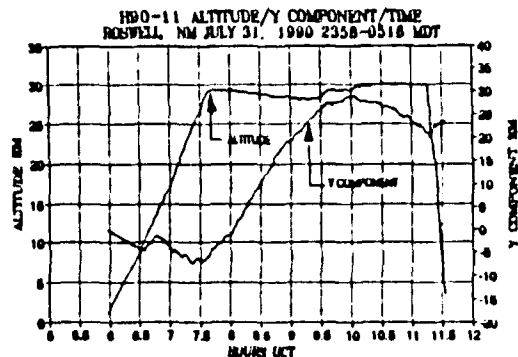


Figure 16. Flight H90-11 was launched from Roswell, NM at 2358 MDT. Note the change in trajectory at 1000 UCT.

9. Discussion

The temperature data collected exhibited some unexpected anomalies in the daytime flights. Because of solar loading and boundary layers effects, elevated daytime temperatures were expected, however, the strong thermal spikes were not. One possible explanation was the orientation of the radiosonde. To test this a radiosonde subjected to strong

incoming solar radiation in front of a closed window in a closed room. Every fifteen minutes the radiosonde was rotated 90 degrees. Temperatures were recorded and compared for each fifteen minute segment. No significant differences were noted in any of the positions. These test data are shown in Table 3.

TABLE 3.

RADIOSONDE SOLAR LOADING TEST

Begin Test Deg C	End Test Deg C	Position
31.4	31.6	Facing sun
30.1	29.9	90 deg left
30.9	30.7	Away from sun
29.2	29.9	90 deg right

Table 3. A test for solar loading was made in a closed room at about 850 a.m. No significant differences were noted. The exposure time at each position was 15 minutes.

although two of the spikes occurred very soon after the balloon had settled into float. These data are shown as a composite summary in Figure 21. It is evident that the temperature deviations are daytime phenomena. Elevated temperatures and fluctuations were expected but the magnitude was surprising. It is interesting to note on Flight H89-21 where the radiosonde was about two feet below the payload, much smaller deviations were measured. However, the mean daytime temperature was much higher above ambient.

An analysis of the trajectory data indicates a correlation between the change in direction and the time of day and/or the geographic location. These changes in direction correlate with the time of the six hour surface pressure nodes at 0300, 0900, 1500, and 2100 local time. These six hour pressure nodes are reflected in the surface pressure as higher pressures at 0900 and 2100 and lower pressures at 0300 and 1500 local time. There is also a weaker correlation with geographic position in that the most frequent change occurred over the Sacramento's ridge crest. It is interesting to note that Flight H90-09 which was flown between pressure node times had no significant changes. These data are shown in Table 4.

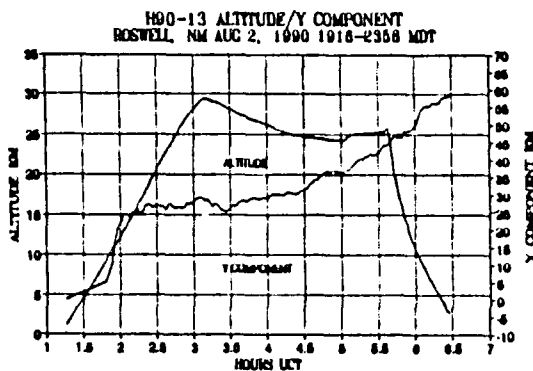


Figure 19. Flight H90-13 was launched from Roswell, NM at 1916 MDT. Note the change in trajectory at about 0330 UCT.

TABLE 4

TRAJECTORY TIME/DISTANCE COMPARISON

Flight Number	Time of Change (MDT)	Dist from Launch Site (KM) (longitude)	Character
H89-21	1000	+40 (105.66)	Veered
H90-08	1500	-75 (105.20)	Backed
H90-09	No Sig	No Sig	
H90-10	0800	-120 (105.83)	Backed
H90-11	0400	-150 (106.08)	Backed
H90-13	2200	-140 (105.90)	Veered

Table 4. This table correlates the time of a significant change in trajectory, the location of the change and the character of the change.

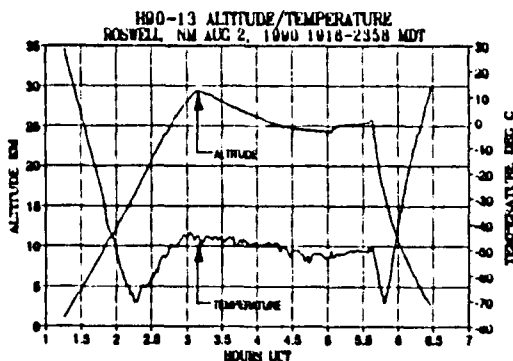


Figure 20. Flight H90-13 was launched from Roswell, NM at 1916 MDT. Note the absence of temperature fluctuations during this period.

These data are shown in composite form in Figure 21. As shown in the graph the largest direction changes occurred at 1000 and 1400 UCT.

These daytime temperature fluctuations appear to be random. No correlation was observed as to geographic location, time of day or time at float,

The amount and type of cloud cover was compared with the altitude, temperature profiles and trajectories by comparing the satellite pictures with the flight data. There was little difference in either type or amount of cloud from flight to flight. Nothing of interest was noted in the cloud analysis.

10. Summary

There appears to be a good correlation between time of day and the change in trajectory which coincides with the time of the six hourly surface pressure nodes. There is a weaker correlation with location. These data are masked by ballast drops and changes in balloon altitude which could also account for the changes. These few data points and masking parameters make the correlation less definitive.

recovery of these systems. In particular my thanks to Joe Longshore and Joe Fumerola for their help in assembling the payload and Jerry Black for assistance in data formatting and analysis. At home my thanks to the shop technicians who built the electronics package and Catherine Rice for assistance in the technical preparation of this paper.

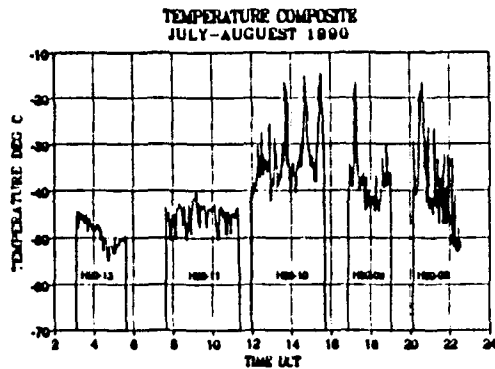


Figure 21. Composite temperature graph for the 1990 Roswell, NM flights. Note the change in temperature fluctuations from night to day.

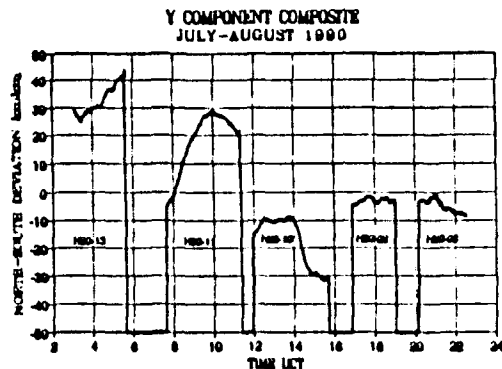


Figure 22. Composite Y-component versus time for the Roswell, NM 1990 flights.

The thermal spikes observed during the daytime flights appear to be real data of unknown origin. They do not fit with the entrainment or boundary layer models. Nor do they correlate with any of the investigated parameters. They are sporadic and short in duration. Further study is needed in this area.

11. Acknowledgements

I deeply appreciate the invaluable assistance received from the people at our field site at Holloman AFB, NM, for their help with the launch, tracking and