Analysis of Reentry Into the White Sands Missile Range (WSMR) for the LifeSat Mission*

N93-24717

154743

p. 14

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ABSTRACT

This study investigates the reentry of the LifeSat vehicles into the WSMR. The LifeSat mission consists of two reusable reentry satellites, each carrying a removable payload module, which scientists will use to study long-term effects of microgravity, Van Allen belt radiation, and galactic cosmic rays on living organisms. A series of missions is planned for both low-Earth circular orbits and highly elliptic orbits. To recover the payload module with the specimens intact, a soft parachute landing and recovery at the WSMR is planned. This analysis examines operational issues surrounding the reentry scenario to assess the feasibility of the reentry.

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* This work was supported by the National Aeronautics and Space Administration (NASA)/Goddard Space Flight Center (GSFC), Greenbelt, Maryland, Contract NAS 5-31500.

1. INTRODUCTION

The LifeSat program is envisioned to employ two reusable reentry satellites (RRS), each carrying a removable payload module (PM), to be used by scientists to study long-term effects on living organisms of microgravity, Van Allen belt radiation, and galactic cosmic rays (GCR). The effects of GCR are separable from those due to Van Allen belt radiation by orbit selection. Both highly elliptical polar and circular near-equatorial orbits will be used to provide the range of environments necessary to perform a comprehensive study. Mission lengths of approximately 60 days will provide full life-cycle observation for some of the organisms. The spacecraft is returned to Earth at the White Sands Missile Range (WSMR) in New Mexico, U.S. for a soft landing to recover the PM containing the specimens intact, and allow the RRS to be refurbished for future missions.

Four missions are currently planned: two highly elliptical orbit missions [200 x 20,600 kilometer (km)], each to place a single RRS in a polar orbit from the Western Test Range (WTR); and two circular orbit missions that will each fly two RRSs at differing altitudes. The circular missions will launch from the Eastern Test Range (ETR) and will have altitudes of 350, 700, and 900 km, with an inclination of 34 degrees. This paper focuses on the reentry phase for all four mission orbits. Operational issues such as burn sequencing, burn errors, range safety, and contingency operations are discussed.

2. REENTRY

WSMR will recover the LifeSat vehicles at the end of each 60-day mission. Execution of a controlled, soft landing and recovery will be done by performing a primary deorbit burn followed by a trim burn to correct for dispersions in the primary burn. Deployment of a parachute system at an altitude of approximately 50,000 feet will then slow the velocity of the spacecraft to allow an impact of less than 10 g's. The spacecraft position will be closely monitored, and with the aid of a homing beacon, ground recovery crews will retrieve the PM within two hours after impact.

The analysis performed for this paper concentrates on both the deorbit and trim burn. The analysis of the primary deorbit burn begins by calculating the nominal delta-v for ballistic reentry of the four mission orbits. The effects of thrust and attitude errors on the deorbit burn are quantified to provide a landing footprint. The off-nominal cases for the deorbit burn are then remodeled with a trim burn to find the delta-v's required to readjust the orbit path to land at WSMR. The trim burn accuracy is then varied to generate a revised landing footprint which includes both off-nominal deorbit and trim burns.

2.1 Nominal Deorbit Burn

The nominal deorbit burn location is defined as the point in the mission orbit that is one half an orbit before passing over WSMR. This was chosen because it requires the minimum delta-v to reenter the spacecraft. Figures 2-1 and 2-2 show the burn points and the nominal reentry paths for the 900 km circular mission and the highly elliptic mission, respectively.

The modeling of the burns and the orbit propogations are performed using the Goddard Mission Analysis System (GMAS). The burns are modeled assuming four 100-pound force hydrazine thrusters with a specific impulse (I_{sp}) of 215 seconds. All burns are assumed to be performed in-plane (yaw angle = 0 degrees, pitch angle = 180 degrees) and are targeted to a landing site at WSMR located at latitude 33.1 degrees north and longitude 253.63 degrees east. Finite burn approximations and fuel consumptions were calculated in GMAS using the rocket equation. The burn data for each of the four mission orbits are listed in Table 2-1.

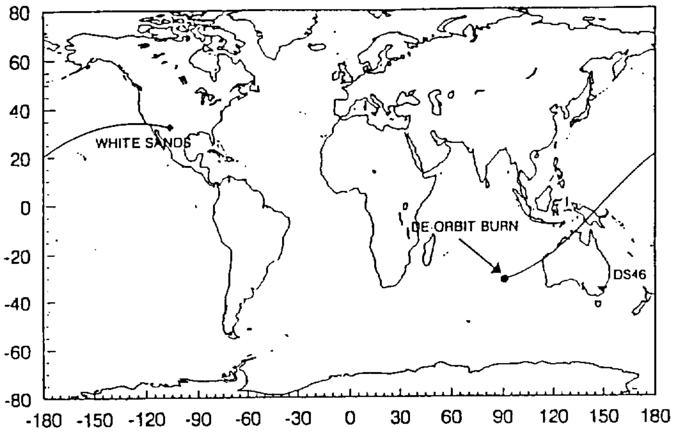

Figure 2-1. LifeSat Reentry Groundtrack 900 km Orbit North-to-South Trajectory to WSMR (Inclination equals 34 degrees)

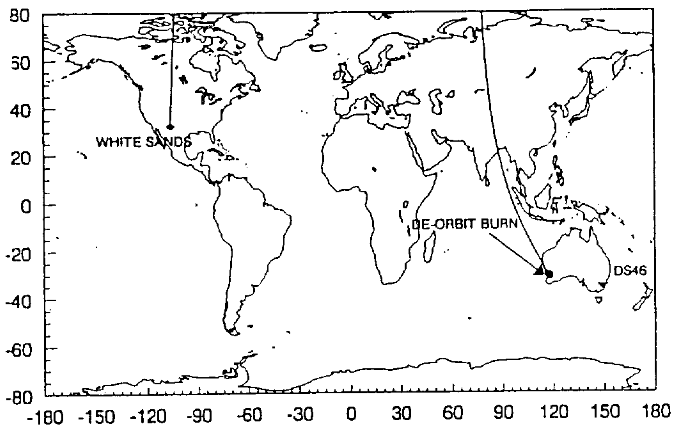

Figure 2-2. LifeSat Reentry Groundtrack 200 x 20,600 km Orbit North-to-South Trajectory to WSMR (Inclination equals 90 degrees)

Table 2-1. Nominal Deorbit Finite Burn Data

MISSION ORBIT DESCRIPTION	DEORBIT DELTA-V (M/SEC)	BURN LENGTH (SEC)	FUEL USED (LBS)
350 km circular	79.8	63.9	118.9
700 km circular	174.6	136.7	254.3
900 km circular	230.0	177.8	330.7
200 x 20,600 km	24.2	19.6	36.5

The deorbit burn which requires the lowest delta-v is the highly elliptic mission. Because the total change in semimajor axis is small, a delta-v of only 24.2 meters per second (m/sec) is needed for spacecraft reentry. For the circular orbits, as the altitude of the orbit increases, the change in semimajor axis from the mission orbit to the reentry orbit increases, resulting in a much longer burn. The largest delta-v, 230.0 m/sec, occurs for the 900 km orbit.

2.1.1 Range Safety

To land at WSMR, the RRS must meet various range safety criteria. The ground tracks of the reentry path and the associated altitudes were studied for the nominal cases. The footprints of various off-nominal cases were also analyzed and are presented in Section 2.2.

The ground tracks of the reentry path are plotted to depict when the spacecraft travels over populated areas. Graphs depicting altitude versus downrange distance from WSMR are generated to be used in conjunction with the ground track plots. These graphs aid in determining safe avoidance of the regions surrounding WSMR as well as in determining the need for the Federal Aviation Administration (FAA) to restrict airspace.

The circular orbit with the lowest reentry altitude is the 350 km case. A north-to-south trajectory was initially chosen for the reentry to avoid overflying Mexico (see Figure 2-1). A more detailed view of this reentry path is shown in Figure 2-3. The reentry path enters the U.S. over the northernmost part of Los Angeles. However, Figure 2-4 shows that at that point in the orbit, the altitude of LifeSat is 230 thousand feet (kft). Once over New Mexico, U.S., the spacecraft passes close to Truth or Consequences. However, although the city is near WSMR, the altitude of the spacecraft is approximately 120 kft.

For the elliptic polar mission, Figure 2-5 shows that LifeSat will reenter from the north. This reentry path does not pass directly over any cities but does pass between Albuquerque and Santa Fe, a region of frequent air traffic. Figure 2-6 shows that the altitude of LifeSat is over 150 kft when passing between the cities. Since airplanes travel at an altitude, of at most, 40 kft, an airspace conflict does not exist. For all cases, LifeSat will not begin to descend below 50 kft until directly over WSMR.

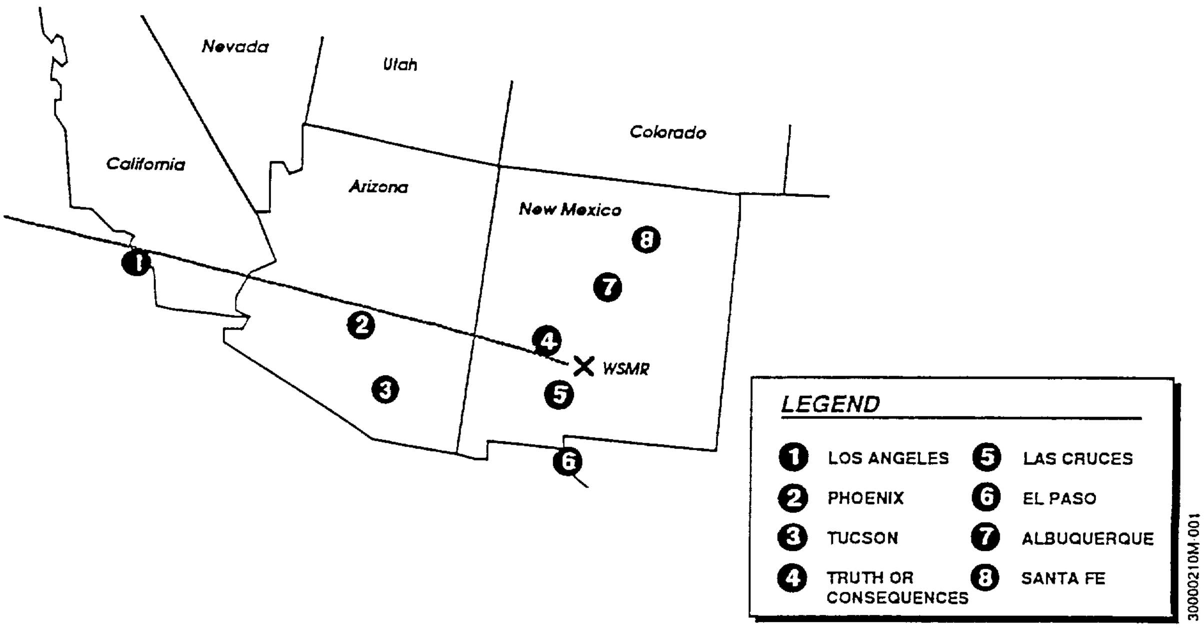

Figure 2-3. Detail Reentry Groundtrack; 350 km Orbit North-to-South Trajectory

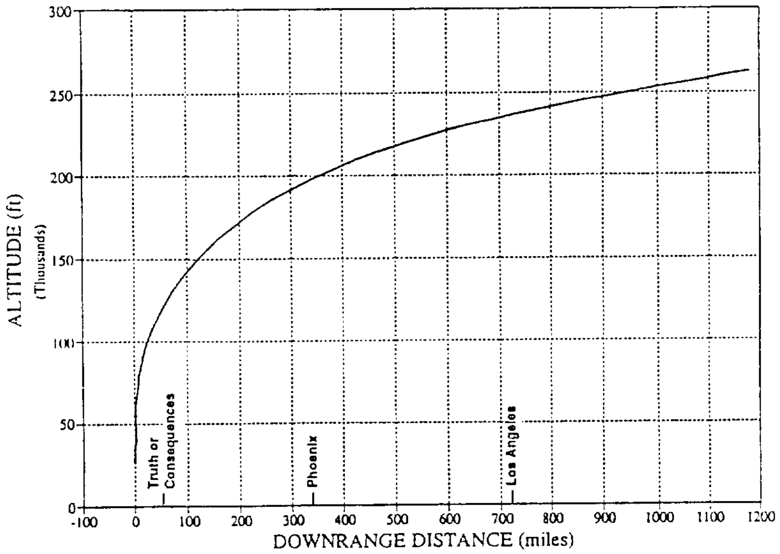

Figure 2-4. LifeSat Reentry Altitude vs. Distance; 350 km Orbit North-to-South Trajectory

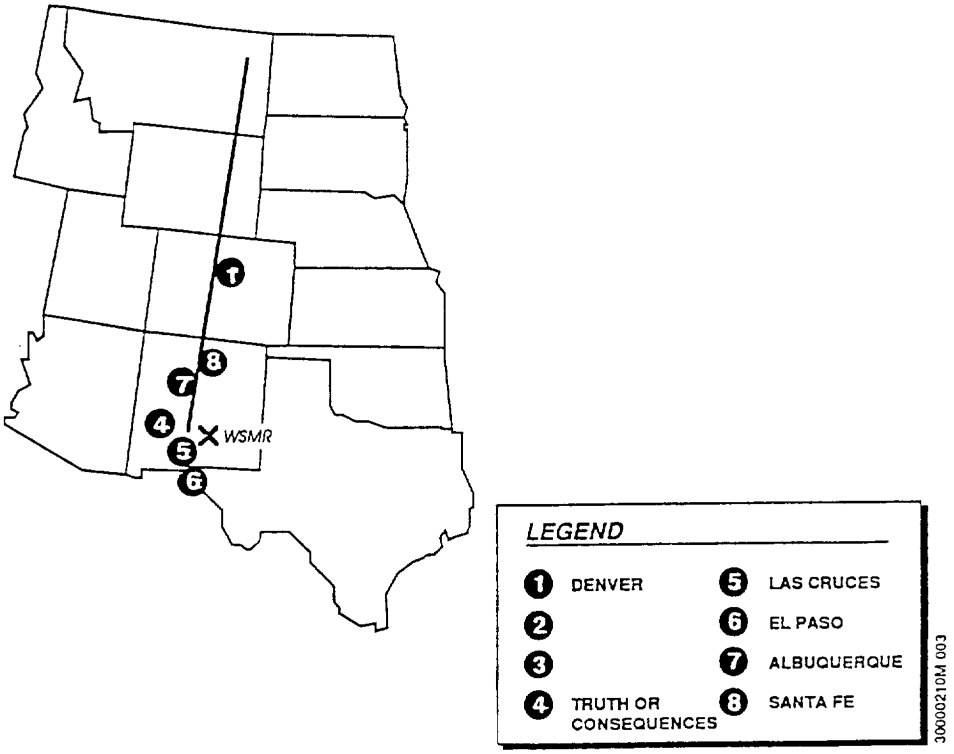

Figure 2-5. Detail Reentry Groundtrack; 200 km x 20,600 km Orbit North-to-South Trajectory

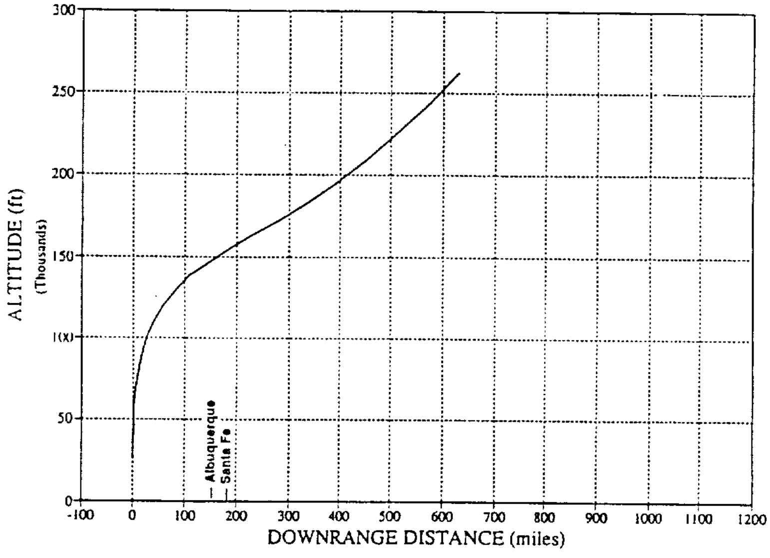

Figure 2-6. LifeSat Reentry Altitude vs. Distance; 200 x 20,600 km Orbit

2.2 Off-Nominal Deorbit Burn: Delta-V Errors

One other major reentry issue is the size of the possible footprint and the accuracies that are necessary to land the spacecraft at WSMR. For LifeSat, the reentry will be performed by two burns: a primary deorbit burn and a secondary trim burn. This section presents the results of an off-nominal deorbit burn and the resulting footprint. Section 2.4 presents the trim burn calculations, which use the results of this section to model the burns necessary to recover from off-nominal deorbit burns.

2.2.1 Circular Orbits

For the 350 km mission orbit, a delta-v of 79.8 m/sec is required to reenter at WSMR. A 3-sigma range of ± 20 percent of the nominal delta-v was tested for the burn; however, only a range of +20 percent to –7 percent reentered (Figure 2-7). If the burn is leaner than 7 percent, the spacecraft skips out and reenters on the following orbit.

The footprint extends from approximately 150 miles west of Los Angeles, California (+20 percent) to just northwest of Puerto Rico (–7 percent). The state of New Mexico is included on the graph to show that an error of only 1 percent will cause the spacecraft to reenter in the neighboring state. In fact, accuracies of approximately 0.75 percent are required to contain the spacecraft reentry to New Mexico.

Currently, no calibration burns are planned for the deorbit thrusters. Therefore, although a 20 percent error would be the maximum error expected, a 5 percent error is likely. If the thrusters are calibrated, a 1 percent error would still be expected, which would still result in a large footprint.

Reentry from the 700- and 900-km orbits are even more sensitive to delta-v errors due to the increase in the nominal delta-v. For the 900-km orbit, the footprint extends about 30 miles farther west than the 350 case, but only reaches Miami, Florida for a cold burn. The east boundary is shortened because a burn error greater than 3 percent cold will not reenter. Furthermore, a burn accuracy of ± 0.5 percent is required to land in the state of New Mexico.

2.2.2 Elliptical Orbit

A nominal deorbit delta-v from the elliptical orbit is 24.2 m/sec. If the burn is 20 percent hot, the spacecraft will land due west of Denver, Colorado, as shown in Figure 2-8. A 10 percent hot burn will result in reentry in

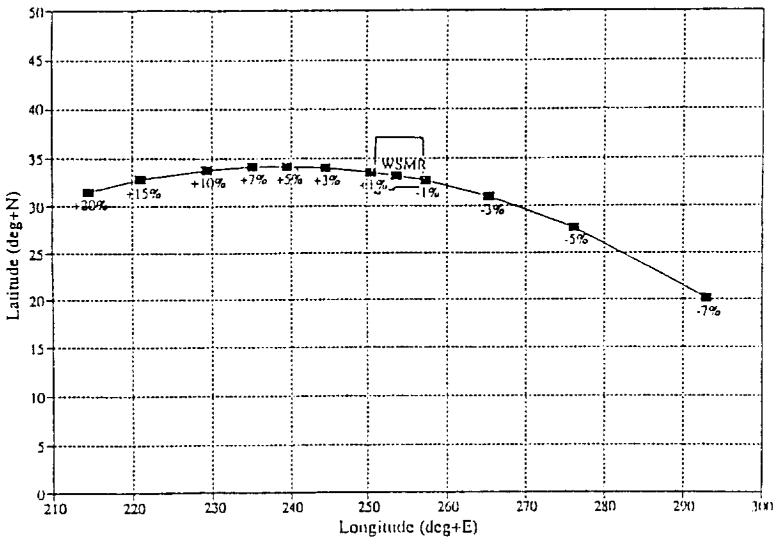

Figure 2-7. Reentry Footprint Delta-v Errors; 350 km North-to-South Trajectory

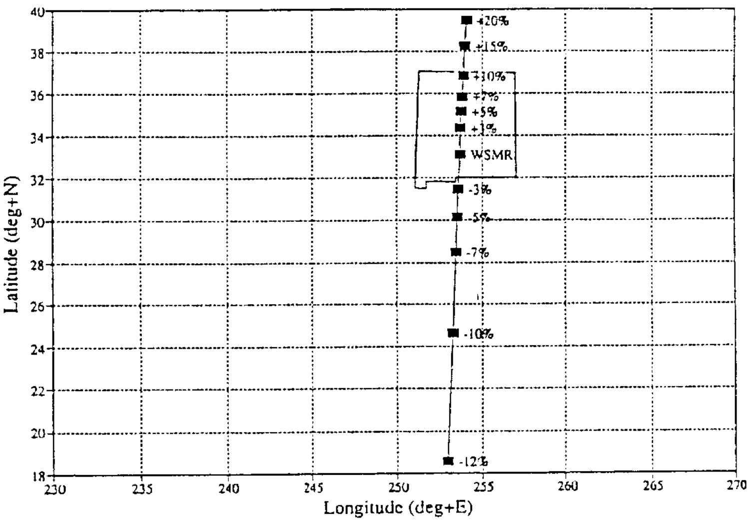

Figure 2-8. Reentry Footprint Delta-v Errors; 200 x 20,600 km; 90 Degrees

New Mexico. If the burn is cold, a –12 percent error is the limit at which the spacecraft will reenter. This extends the footprint into Mexico to a point just south of Guadalajara.

For both the circular and elliptic cases, the size of the footprint may be reduced by reentering at a steeper flight path angle. This is accomplished by lowering the perigee in the reentry orbit. Therefore, to still reenter at WSMR, the deorbit burn must occur later than the current nominal position. In similar studies, such as the Earth Observing System (EOS) reentry analyses, reducing the perigee by 100 km decreased the size of the footprint by 43 percent.

There are disadvantages to lowering perigee. The deorbit delta-v will increase due to the larger change in the semimajor axis. Firing late also decreases the time between the deorbit and trim burns. This is crucial because of the time required to assess the deorbit burn and plan the trim burn. Finally, the g forces experienced by the spacecraft will increase because the flight path angle at the atmospheric interface will increase. Further analysis is needed on the alternative trajectories to be able to measure the various trade-offs.

2.3 Off-Nominal Deorbit Burn: Attitude Errors

In addition to thrust errors, misalignments in the yaw and pitch angles were also analyzed. Figures 2-9 and 2-10 show the results of yaw and pitch errors of ± 3 degrees on the thrust vector for the 350 km and 900 km mission orbits. (The case of the polar orbit is not shown because yaw and pitch errors of ± 3 degrees do not perturb the spacecraft out of the missile range.)

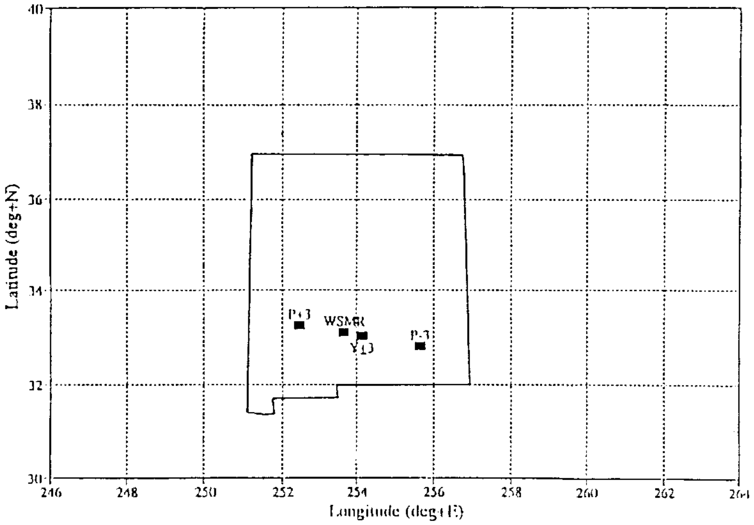

Figure 2-9. Reentry Footprint Yaw and Pitch Errors (Degrees); 350 km North-to-South Trajectory

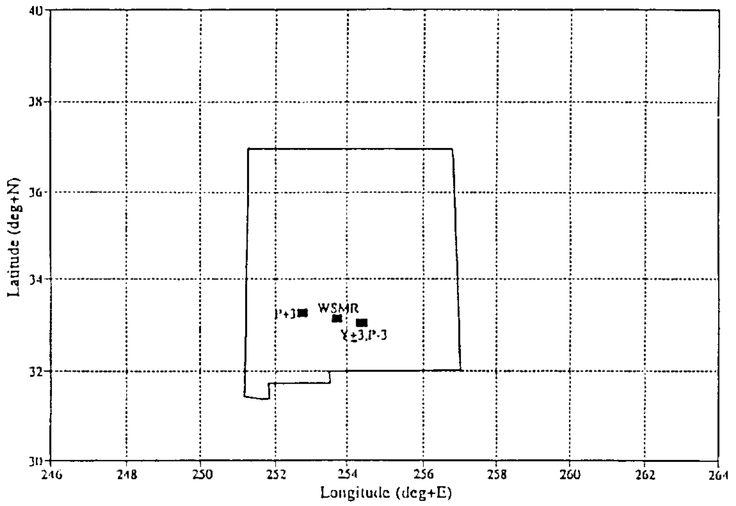

Figure 2-10. Reentry Footprint Yaw and Pitch Errors (Degrees); 900 km North-to-South Trajectory

In both cases, yaw angle errors (out of plane errors) of both ± 3 degrees cause the spacecraft to impact in the identical position. This occurs because the out-of-plane component of velocity is not large enough to perturb the plane of the orbit and is therefore negligible. Consequently, the only effect on the spacecraft is a small reduction of the magnitude of the in-plane vector; thus, the impacts are the same for both ± 3 degrees. Furthermore, this result is comparable to a thrust error, because the only effect is to reduce the in-plane velocity vector. The effects are greater for the 900 km orbit because the nominal delta-v is larger.

An error in the pitch angle rotates the line of apsides, causing an along-track error. This error is more predominant for the 350 km orbit than for the 900 km orbit. Although the delta-v is less for the 350 km orbit, the eccentricity of the reentry orbit is less. Consequently, the orbit is more sensitive to a change in the line of apsides.

Both yaw and pitch errors affect the impact point only in the along track direction. The magnitude of the errors are also small in proportion to the delta-v errors previously discussed. For future analysis, a delta-v error will be applied to the nominal burn that is intended to encompass all three types of errors.

The burn errors studied show two major results. First, the accuracy of the deorbit burn is crucial in executing a landing at WSMR. Each of the footprints is large, and shows that the spacecraft is especially sensitive to cold burns. Therefore, a method must be developed to control the burn. One possible method is through the use of accelerometers. These instruments may be used to measure the burn to a high degree of accuracy and can be used to command the thrusters to shut off once the nominal value of thrust is reached.

The second result of the analysis is the need for a trim burn. An accurate landing requires a near perfect burn. Despite all precautions, some alternative measurements of the success of the burn [such as a Global Positioning System (GPS) generated ephemeris solution] should be employed to model and assess the deorbit burn and to calculate the trim burn if necessary.

2.4 Trim Burn

Once the deorbit burn is completed, a new orbit solution must be computed to determine the success of the burn. If the burn was not acceptable, a trim burn will be executed using the attitude thrusters to correct the burn error.

2.4.1 Burn Data

In this analysis, the attitude thrusters are modeled using 30 lbs of thrust with an Isp of 220 seconds. For the circular mission orbits, the trim burn is modeled 15 minutes after the deorbit burn. For the elliptic orbit, a trim burn is modeled 30 minutes after the deorbit burn.

Tables 2-2 and 2-3 summarize the results for the trim burns that are needed to recover from various off-nominal deorbit burns. For all cases, a recovery is possible with one in-plane burn (yaw angle of 0 degrees) that is along the velocity vector (pitch angle of 0 or 180 degrees).

Table 2-2. Trim Burn Recovery Data for the 200 x 20,600 km Mission Orbit

DEORBIT BURN ERROR (DELTA-V, ATTITUDE)	YAW ANGLE (DEGREES)	PITCH ANGLE (DEGREES)	DELTA-V (M/SEC)	BURN LENGTH (SEC)
DV-5 Percent	0	180	1.3	13.6
DV+5 Percent	0	0	1.2	13.3
DV-10 Percent	0	180	2.5	27.2
DV+10 Percent	0	0	2.5	27.2
DV-20 Percent	0	180	5.0	54.1
DV+20 Percent	0	0	5.0	54.1

Table 2-3. Trim Burn Recovery Data for the 900 km Mission Orbit

DEORBIT BURN ERROR (DELTA-V, ATTITUDE)	YAW ANGLE (DEGREES)	PITCH ANGLE (DEGREES)	DELTA-V (M/SEC)	BURN LENGTH (SEC)
DV-5 Percent	0	180	17.2	186.3
DV+5 Percent	0	0	17.0	184.2
DV-10 Percent	0	180	32.5	350.9
DV+10 Percent	0	0	34.5	372.3
DV-20 Percent	0	180	67.5	722.8
DV+20 Percent	0	0	70.3	752.3
Yaw-3 Degrees	0	180	0.6	6.5
Yaw+3 Degrees	0	180	0.6	6.5
Pitch-3 Degrees	0	180	1.4	15.2
Pitch+3 Degrees	0	0	0.6	5.4

As noted in the footprint analysis in the previous section, thrust and attitude errors cause impact to occur either before or after crossing WSMR along the orbit path. For cases where the impact occurs before reaching WSMR, the deorbit burn is greater than the nominal value. Therefore, the trim burn should occur opposite to the deorbit burn, or pitch angle equal to 0 degrees. If the impact occurs past WSMR, the deorbit burn is not strong enough, and more delta-v should be added with a pitch of 180 degrees.

If a thrust error occurs during deorbit from the elliptical orbit, a trim burn could be executed to correct all expected dispersions. Table 2-2 shows that for the worst case scenario of a ± 20 percent burn error, a trim burn would require 5 m/sec delta-v (54 seconds duration), which is an acceptable load on the attitude thrusters. For the circular missions, however, the size of the trim burn is much larger. For the 900 km orbit (see Table 2-3), ± 5 percent burn error would require a trim burn of 3 minutes while a ± 20 percent error recovery would last 12.5 minutes.

The size of the trim burn increases proportionally to the size of the nominal deorbit burn. Therefore, the circular orbit cases could require larger trim burns than the elliptic orbit case. If the large errors occur in the circular missions, the trim burns may be too large for the attitude thrusters. This again shows the need for a tightly controlled deorbit burn.

2.4.2 Trim Burn Footprint

The attitude thrusters used in the analysis are assumed to have been calibrated during the mission. Therefore, burn errors of ± 5 percent were used to model worst-case estimates of both thrust and attitude errors. The results of the revised footprints are shown in Figures 2-11 and 2-12 for the elliptic mission and the 900 km circular mission, respectively.

The elliptic mission required a deorbit delta-v of only 24.2 m/sec. For a 20 percent error during the deorbit burn, the trim burn delta-v required is 5 m/sec. If a 5 percent error occurs during the trim burn, the delta-v lost is 0.25 m/sec. Consequently, the footprint is expected to be small. In addition, LifeSat will reenter directly from the north. Since WSMR is aligned north-to-south, LifeSat has a large area in which to land. As a result, Figure 2-11 shows that the worst case scenarios of ± 20 percent and ± 5 percent errors in the deorbit (primary) burn and trim burn, respectively, will keep the landing of LifeSat at WSMR.

Reentry from the circular orbits require larger delta-v's in the deorbit burn, and potentially in the trim burn. Therefore, a larger footprint is expected for the circular orbit missions with the largest occurring for the 900 km reentry. Figure 2-12 shows that for the 900 km orbit, the footprint extends outside of New Mexico for large primary burn errors coupled with a 5 percent trim burn error.

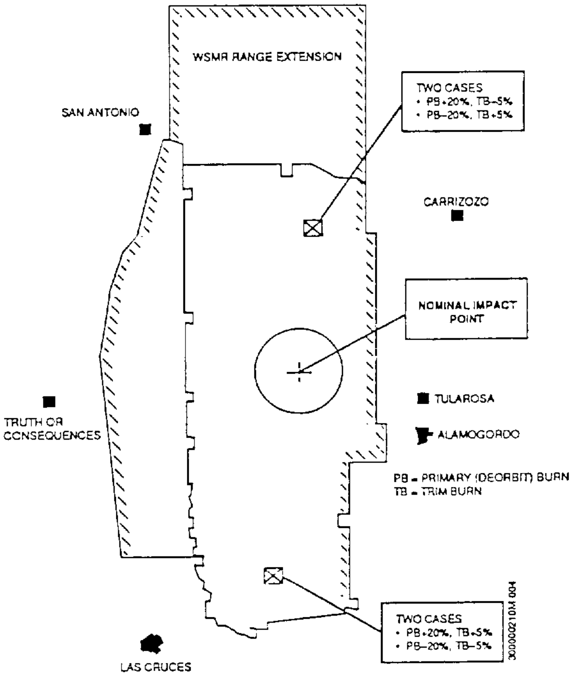

Figure 2-11. Reentry Footprint with Trim Burn Error, Elliptical Mission

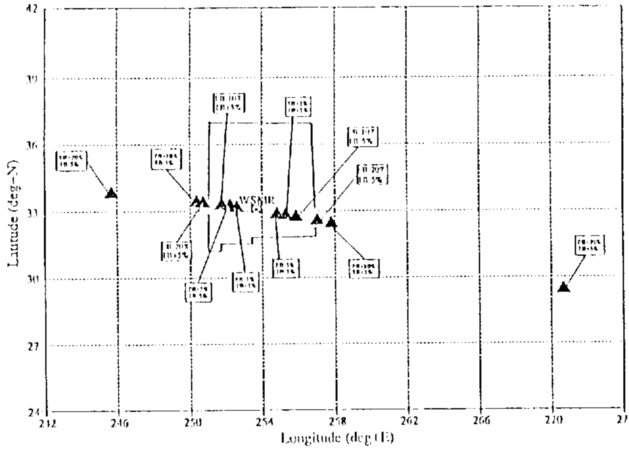

Figure 2-12. Reentry Footprint with Trim Burn Error, 900 km North-to-South Trajectory

In addition to the large footprints shown, the reentry path approaches WSMR from the west; this requires impact in the narrow region of WSMR. These factors combined indicate that the accuracy requirements for the trim burn are quite rigid. Sample accuracies were found for both the 350 km and 900 km circular orbits following ± 5 percent deorbit burn errors.

To recover from ± 5 percent primary burn errors and land in WSMR (not including extensions), the trim burn must be within a 2 percent accuracy for the 350 km mission and 1 percent accuracy for the 900 km mission. As the deorbit burn error increases, the accuracy requirement of the trim burn will tighten. However, an error of at least 1 percent is still quite likely even if the attitude thrusters are fairly well calibrated. Therefore, these preliminary results indicate that the deorbit burn accuracy must be well within 5 percent. This again shows the need for a tightly controlled burn.

3. LANDING CONTINGENCIES

The dependency on favorable weather is a concern for the parachute landing and ground recovery team. Certain variables in reentry planning, i.e., time of day and time of year, have been chosen to reduce the likelihood of unfavorable weather; however, some degree of uncertainty will always exist. Therefore, it is imperative to design a contingency plan for employment in the event of a landing waveoff.

Two elements were considered in the design of the contingency plan. First, since the waveoff cannot be preplanned, the duration of the delay from decision to execution will be variable. Therefore, the contingency plan needs to be flexible to allow a time for the next opportunity. Second, the spacecraft operates under rigid power constraints that require the next attempt to occur within a few days. Consequently, the contingency plan must allow for a second reentry attempt within 1 to 5 days. With these restrictions, a contingency maneuver plan was developed.

In addition to creating a contingency plan for waveoffs, one additional requirement levied by the project is the ability to command spacecraft reentry prior to 60 days. To accomplish this, an approach similar to the waveoff plan may be used. For both contingency applications, reentry is not immediate. Once the contingency maneuver is planned and executed, a new orbit solution must be obtained. From this solution, a new reentry plan may be developed. This process may require two or more days.

3.1 Elliptic Mission

3.1.1 Waveoffs

The orbit of the highly elliptic mission is designed to place perigee over WSMR at the end of the 60 day mission. If a waveoff occurs, LifeSat will travel near WSMR the following day, however, the groundtrack will have shifted slightly. If the waveoff condition exists for several days, this shift will accumulate to a groundtrack error of over 4 degrees in 5 days. An out-of-plane burn would then be needed to correct the accumulated error; this is not feasible under the current fuel budget.

One approach to the problem is to maintain the groundtrack once it has reached the WSMR location. This is done by adjusting the semimajor axis to change the orbit period to create a repeating groundtrack. Operationally, after waveoff has occurred, a maneuver executed at the perigee pass over WSMR will lower apogee by approximately 30 km. This will fix the groundtrack over WSMR once per day.

Although this method will align the groundtrack to the proper location, it does not fix the perigee location. Due to the Earth's geopotential field, the perigee of the orbit will rotate northward. However, perigee will rotate 2 degrees in 5 days which should not impair reentry.

3.1.2 Early Return

A similar approach may be used in the event of an early return. The semimajor axis must be altered to align the groundtrack for a reentry attempt. The nominal mission orbit is designed such that the groundtrack will advance to WSMR after 60 days. If a return is necessary prior to 60 days, elimination of the difference between the current longitude of the groundtrack and the longitude of WSMR must occur by lowering apogee to increase the groundtrack advancement. The rate of advancement will increase as the altitude of apogee decreases. Therefore, the magnitude of the contingency maneuver depends on the mission elapsed time and the urgency of the return.

In addition to the groundtrack advancement, the line of apsides must also advance to WSMR. As with the groundtrack, the natural rotation is planned for a 60 day mission. Therefore, the contingency maneuver must also rotate the line of apsides. Since the contingency maneuver will need to accomplish two goals on a limited fuel budget, an early return may not be possible for the early stages of the mission. Further analysis must be performed to determine how early a reentry is feasible.

3.2 Circular Missions

3.2.1 Waveoffs

In the event of waveoffs for the three circular missions, the semimajor axis could be adjusted to create a repeating groundtrack. However, the circular missions are inclined at 34 degrees. This causes a much greater shift in the groundtrack due to the precession of the nodes from perturbations by the second zonal harmonic, J_2. As a result, the semimajor axis may need a larger change. Consequently, a slightly different approach is taken in the contingency plan.

For the elliptic polar mission, a daily repeat ground track is the simplest method to employ. However, for the circular missions, a wider range of alternative solutions is needed. Repeat cycles of 1 to 5 days were determined for each mission for an eccentric orbit with apogee fixed at the mission altitude. In this way, a perigee lowering maneuver would occur in place of the deorbit burn followed by a small adjustment maneuver to place perigee over WSMR.

The advantage of perigee lowering is that no additional delta-v is required. Recall that the function of the reentry burn is to lower perigee close to the earth so that the atmosphere can pull the spacecraft to the ground. If the deorbit burn from the mission altitude is done in two perigee lowering burns, the total delta-v for the two burns is equivalent to a single deorbit burn.

Table 3-1 shows perigee altitudes needed to achieve a repeat cycle for each of the three mission altitudes. Lowering perigee to 312.1 km is apparently the best candidate for the 350 km mission orbit. This solution will allow for a reentry attempt every 2 days. A return to WSMR after 1 day is not feasible.

Table 3-1. Elliptical Repeat Groundtrack Cycles

MISSION ALTITUDE	NUMBER OF DAYS IN REPEAT CYCLE	PERIGEE ALTITUDE REQUIRED (KM)
350 KM	1	17.5
350 KM	2	312.1
350 KM	3	212.3
350 KM	4	162.9
350 KM	5	252.0
700 KM	1	271.6
700 KM	2	598.6
700 KM	3	487.6
700 KM	4	432.9
700 KM	5	666.1
900 KM	1	743.8
900 KM	2	398.2
900 KM	3	511.3
900 KM	4	923.9
900 KM	5	887.5

Both the 700 and 900 km orbits can maneuver least to a 5 day repeat cycle. However, power requirements may not last the full 5 days, thus a larger contingency maneuver may be required. For the 700 km orbit, the next best solution is for a 2 day repeat cycle; the next best solution for the 900 km orbit is a 1 day repeat cycle. For all contingency solutions, the rotation of perigee is not a concern. Perigee will rotate, on average, approximately 1 degree in 5 days.

3.2.2 Early Return

An early return during the majority of the mission should be feasible because the groundtrack frequently passes near WSMR. A groundtrack correction maneuver is still necessary to adjust the groundtrack precisely over WSMR. In addition to the north-to-south crossings, reentry possibilities may be gained through the use of a south-to-north trajectory over the Baja region of Mexico. Future analyses should address the frequency of the early landing opportunities based on the fuel budget of the 900 km mission orbit.

4. CONCLUSIONS

The reentry analysis concentrates on the deorbit burn for both nominal and off-nominal conditions. One of the LifeSat project Phase B reports suggests the use of a solid fuel deorbit motor. The present analysis shows that very small variations in the delta-v from the deorbit burn can cause extremely large variations in the landing footprint. Since it is not possible to control the burn of a solid fuel rocket motor, this suggests that: (1) a liquid fuel deorbit motor controlled by an accelerometer is needed, and (2) a trim burn using the attitude thrusters is also required. Since a trim burn is necessary, the tolerable variation in the trim burns that would allow LifeSat to safely reenter over WSMR was analyzed.

The landing at WSMR must occur in weather conditions that meet certain criteria; therefore, a waveoff situation is quite possible and must be accommodated. Since the experiments and the spacecraft life support system operate within a fairly tight set of defined time constraints, this would require that the next reentry attempt occur within a few days. Consequently, contingency plans were examined that would allow another reentry within 1 to 5 days. A technique of adjusting the apogee to cause the groundtrack to repeat is proposed for the elliptical orbit. A perigee lowering maneuver is recommended to create a repeating groundtrack for the circular missions. Several scenarios are presented.

If an emergency occurs requiring an early reentry, the orbit must be adjusted to allow for a reentry attempt. Similar maneuver strategies would be employed to align the groundtrack over WSMR. In addition, for the elliptic case, perigee would need to be positioned over WSMR.

REFERENCE

Computer Sciences Corporation, CSC/TM-91/6159, *LifeSat Mission Analysis Report*, D. W. Denzler, M. E. Hametz, and L. J. Roszman, November 1991