RISK ANALYSIS MODEL FOR THE ASCENT PHASE OF SCIENTIFIC BALLOON OPERATIONS

by

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(ABSTRACT)

The National Scientific Balloon Facility (NSBF) conducts scientific balloon flights. Scientific payloads ranging from a few hundred up to several thousand pounds suspended weight are flown over the southern United States. People living in these areas are subject to risk from these operations.

A model has been developed to predict the risk associated with the ascent phase of a balloon operation. This model includes all of the significant factors that affect ascent phase risk. The model is automated in a computer program whose input contains all of the parameters and factors for a particular mission.

The results of this model can be used to advise management personnel of the risk level for a particular balloon mission. This model can be used as a long range planning tool or on the day of launch to determine whether the mission risk level is acceptable.

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I. STATEMENT OF PROBLEM

A. BACKGROUND

The National Scientific Balloon Facility (NSBF), located in Palestine, Texas, conducts scientific balloon flights. Scientific payloads ranging from a few hundred up to 6000 pounds suspended weight are flown over the southern United States. During recovery, payload and balloon impacts are planned in areas of low population densities; however, mission failures can result in an impact in a more densely populated area.

NASA/Wallops Flight Facility, located at Wallops Island, Virginia, manages the NSBF. This includes flight safety responsibility for NSBF operations. The Safety and Quality Assurance Engineering Branch at NASA/Wallops advises the Director of Suborbital Projects and Operations of the risk level inherent in these operations.

An initial safety analysis was performed on the NSBF balloon operations shortly after NASA assumed management responsibility (5). It was found that the NSBF personnel were safety conscious and that their operational safety procedures were acceptable. However, the quantitative risk analysis revealed that the risk level inherent in heavy payload balloon operations exceeded the risk level commonly accepted for NASA flight operations. Analysis showed that this was due not only to the fact that these flights were conducted over populated areas but also due to the high failure rates associated with the heavy payload missions.

B. APPROACH TO THE PROBLEM

An initial model is constructed to calculate mission risk by Beyma (6). Risk is evaluated for two general categories of missions: heavy payload and non-heavy payload missions. Average historical failure rates for these two categories and average population densities over a county or state are used. Several basic operational risk reduction steps are included. This model is useful for general risk evaluation and as a long range planning tool. This initial quantitative analysis reveals that over 80% of the mission failures occur, and approximately 50% of the total mission risk is incurred, during the ascent phase.

The analysis by Beyma (6) is macroscopic and considers a total mission. This analysis concentrates on the ascent phase of a balloon operation. A more detailed and accurate risk calculation for the ascent phase is performed here. Major additions or refinements to the existing model include:

1. Entering specific mission data such as payload/balloon size and weight, ascent rate, and time of day of launch. The initial model uses average size and weight numbers for a range of past balloon missions. The more detailed model uses the size and weight specifications for a specific mission.

2. Constructing a population data base which contains the distribution of the population in the ascent area. City, county, and state population data are obtained from the 1980 U.S. census reports (30). The balloon model includes a population growth factor from 1980 to the current year.
3. Determining the predicted failure rate and altitude distribution for specific missions from payload/balloon data and historical failure rate data. Failure rate, type of failure, and altitude distribution of the failure are obtained from NSBF flight history records (18). The Wallops Balloon Branch maintains statistical records on these failures. The Wallops Safety Branch evaluates this failure rate data and determines how to incorporate it into the risk model. Presently, the failure rate is treated as a function of payload weight. Recent studies indicate that the balloon stress factor may be a better indicator of failure likelihood. Balloon Branch personnel have recently authored two papers on this subject (17, 28). This work includes evaluating the use of the stress factor in determining failure rates and evaluating the reliability of the flights since 1986 using a new balloon material.
4. Determining the predicted position of the balloon at any time during ascent using the ascent rate and the wind profile in the ascent area. The wind profile is determined from radiosonde data. The NSBF has a meteorological office and can launch radiosondes prior to a mission to collect wind profile data.

The balloon climb rate together with the wind profile enable a time history of the position of the balloon during ascent to be predicted.

5. Determining the descent vector which defines the predicted impact area. The wind profile and the ballistic coefficient of the payload/chute enable a descent vector to be calculated from any altitude.
6. Determining the impact dispersion of the payload and the balloon. Predicted versus actual descent vector records are maintained by the NSBF (18).
7. Examining the effects of certain operational safety procedures or mission constraints on the ascent phase risk. Much of the information on NSBF operational procedures was obtained during two visits to the NSBF and discussions with their engineering and operations personnel.

C. FINDINGS

An improved mathematical model that incorporates all of the above additions and refinements is defined. This model includes all of the significant risk parameters and risk reduction factors that affect ascent phase risk. The model is automated in a computer program whose input contains all of the parameters and factors for a particular mission. The population data base is accessed by this program. The program computes the predicted ascent trajectory and the casualty expectation risk for the ascent phase.

The results of this model will be used to advise NASA management of the risk level of a particular balloon mission. As a result of this analysis, some operational constraints may be imposed on the mission to reduce the mission risk to an acceptable level.
The results of this model will also be used to document the mission risk for heavy payload balloon launches. In developing the upgraded model, several new facts were discovered.

1. The probability of balloon failure no longer varies significantly with payload weight. The present failure rate is nearly constant for balloons with a stress factor less than 2700.
2. The probability of balloon failure varies with altitude. The balloon is more likely to fail when ascending through the low temperature region of the troposphere.
3. The state of Texas, where most of the balloon operations are conducted, has experienced an 18% population growth during the past eight years.
4. The payload and balloon impact dispersion values were calculated from historical descent vector records.

II. LITERATURE REVIEW

There exists an extensive reliability literature. Within that literature are included the reliability methodology and equations that are used here (4, 12, 14). In general, the reliability literature does not consider risk in the same sense as is used here.

There is a limited risk analysis literature. Within that literature are found various definitions and discussions of risk (12, 14, 15). In general, the risk analysis literature does not present risk analysis in the same manner as the term is used here.

There exists a limited literature on scientific balloon operations. The majority of this literature pertains to general balloon operations and scientific topics in ballooning (1, 3, 8, 13, 17, 24, 26, 28).

There is a limited literature on operational flight safety analysis. Parker (20) discusses operational rocket flight safety. Beyma (7) discusses both rocket and balloon flight safety. Coombs (10) addresses orbital debris reentry hazard analysis.

There exists a very limited literature on balloon flight safety risk analysis. Beyma (5) discusses balloon operations at the National Scientific Balloon Facility. Beyma (6) presents a quantitative risk model for balloon operations. A major weakness of this model is lack of detail particularly during the ascent phase during which over 80% of the balloon failures occur (18).

Earlier efforts do not address risk analysis for a specific balloon mission. They do not consider the actual distribution of population in the ascent area nor the wind profile on the day of launch. These efforts also do not consider the altitude distribution of balloon failures.

III. MODEL DEVELOPMENT

A. NOMENCLATURE

A number of specialized terms and concepts are used within this document. The following nomenclature establishes a standard vocabulary for this model.

ASCENT VECTOR - The horizontal displacement vector of an ascending object from the launch site to a specified altitude.

BALLISTIC COEFFICIENT - a number describing the descent characteristic of an object on a parachute by combining the weight of the object and the aerodynamic drag coefficient and reference area of the parachute.

BALLISTIC WIND - the average wind velocity vector over a specified altitude range.

CASUALTY EXPECTATION - the expected number of casualties due to the conduct of a mission.

COMMONLY ACCEPTED RISK LEVEL - 1.0×10^{-6} casualties per mission.

CONTROLLABILITY - the degree of control that can be exercised over the payload/chute or the balloon following a failure.

DESCENT VECTOR - the horizontal displacement vector of a descending object from the flight termination point to impact.

DETECTABILITY - the ability of people outdoors to detect a descending object and get out of the way.

DISPERSION - the statistical deviation of the actual impact point from the predicted impact point.

LETHAL AREA - the "footprint" of an impacting object.

PICKLING - the commanded release of the payload from the chute prior to impact.

POPULATION DENSITY - the number of people per square mile.

PROBABILITY OF IMPACT - the probability of an object impacting in a defined area.

RADIOSONDE - an instrument for the measurement and transmission of meteorological data while moving vertically through the atmosphere.

RISK - the likelihood of a particular unplanned and undesired outcome.

STRESS FACTOR - a number describing the stress on a balloon due to balloon geometry, materials, and loading.

B. MISSION RISK

The basic unit of risk used to determine the degree of safety of a balloon mission is casualty expectation. Operational safety procedures and mission constraints are implemented to reduce the mission risk to an acceptable level. The basic risk equation is:

$$CE = P_I \cdot P_D \cdot A_L \qquad \text{(B.1)}$$

where

CE = casualty expectation

P_I = probability of impact

P_D = population density

A_L = lethal area

Figure 1 shows a balloon ascent trajectory and a payload/chute descent trajectory from the point of balloon failure.

BALLOON ASCENT TRAJECTORY AND PAYLOAD/CHUTE DESCENT TRAJECTORY

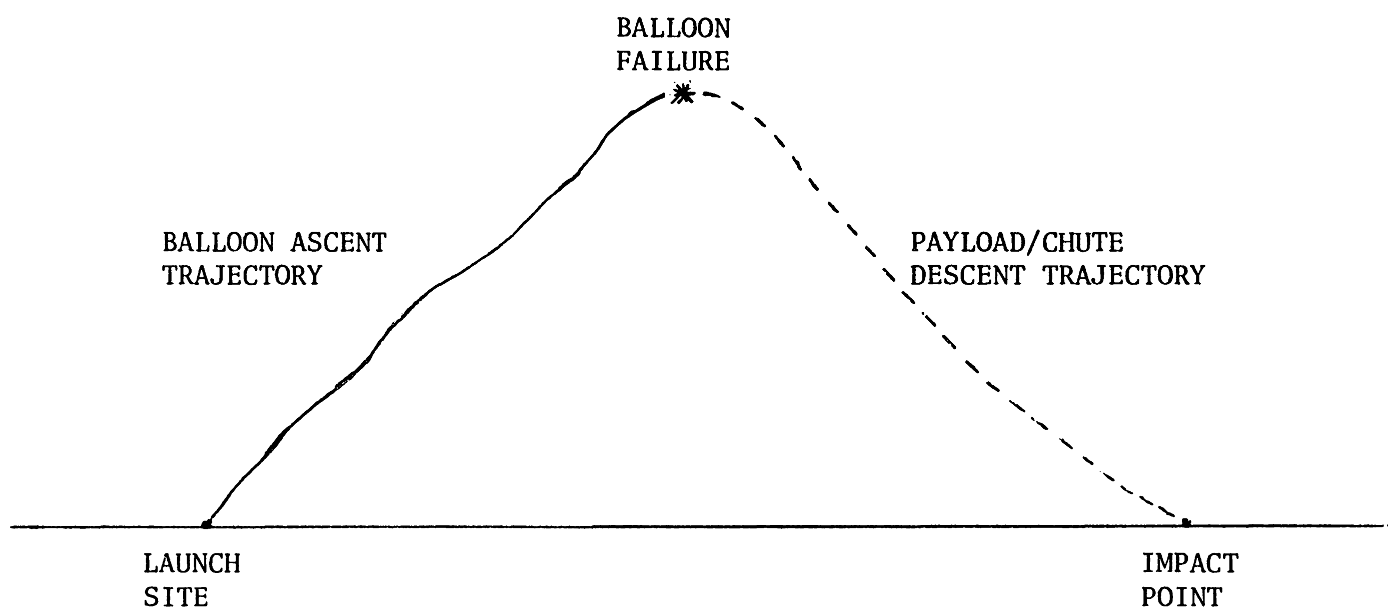


FIGURE 1

An impact will occur during the ascent phase only if a failure occurs which results in flight termination. Depending on the controllability of the balloon and payload/chute after the failure, there are a number of risk reduction steps that can be applied. The risk equation for the ascent phase is:

$$CE = \sum_i \sum_j (F_{A_{ij}}) \ (P_{D_j}) \ (A_L) \ (R_{A_i}) \qquad (B.2)$$

where

F_A = probability of failure during ascent. An impact occurs during the ascent phase only if a failure occurs that results in flight termination. The i subscript indicates the type of failure. This will determine the degree of controllability existing after the failure. The j subscript indicates the position of the balloon when the failure occurs. This will determine the descent vector and the predicted impact point.

P_D = the population density in the predicted impact area.

A_L = lethal area.

R_A = the risk reduction factor. The degree to which some or all of the risk reduction steps can be applied depends on the controllability of the balloon and the payload/chute after a failure occurs.

The casualty expectation risk is summed over discrete altitude intervals. The probability of failure is calculated for each altitude interval. Since there are two descending objects following flight termination, i.e., the balloon and the payload/chute, the total casualty expectation is

CE (TOTAL) = CE (BALLOON) + CE (PAYLOAD)   (B.3)

C. RISK PARAMETERS

The following components affect the predicted risk during the ascent phase.

1. Probability of Failure During Ascent (F_A)

- Weight of the balloon/payload.
- Balloon stress factor.
- Type of failure (determines controllability).
- Altitude.
- Balloon material and manufacturer.

2. Population Density (P_D)

- Population distribution.
- Position of balloon when failure occurs.
- Wind profile.

3. Lethal Area (A_L)

- Size of the balloon.
- Size of the payload.

4. Risk Reduction Factor (R_A)

a. Prelaunch

- Not launching if the predicted ascent trajectory overflies certain densely populated areas.
- Not launching during inclement weather.

- Assuring that a tracking aircraft is available to perform air surveillance and pickling.

b. During Operation

- Avoiding densely populated areas when terminating the balloon flight.
- Air surveillance of the predicted impact areas.
- Pickling capability.
- Personnel detecting the descending objects and avoiding them.
- Protection provided by structures against impacts.

D. COMPUTER MODEL

1. Introduction

A computer model is constructed to calculate the ascent risk by integrating the casualty expectation throughout the balloon ascent. The risk for each altitude is calculated by ascending to the desired altitude, determining the probability of failure at that altitude, calculating the descent vector, and determining the casualty expectation risk of impacting at that point. The nomenclature used in the equations in this section are the variable names from the computer model code. These variable names are defined in Appendix 1. A listing of the computer program is included in Appendix 2.

2. Altitude

An altitude interval of 2000 feet was selected for the integration. This interval represents less than 2% of the 100,000 - 130,000 foot float altitude to which most scientific balloons ascend.

$$ALT = ALT + DELALT \qquad (2.1)$$

3. Dispersion

If a failure occurs during ascent, the nominal impact point is defined by the descent vector from the point of failure. Due to variations in the wind profile, the actual impact point will vary about the predicted impact point. Dispersion is the statistical deviation of the actual impact point from the predicted impact point. It is used to calculate the probability of impacting within a given distance of the nominal impact point. This distance is expressed as a sigma value (7).

Payload and balloon impact dispersions are obtained from a statistical analysis of actual versus predicted descent vectors for NSBF balloon operations (32). Flight history records indicate that the descent vector dispersion is proportional to the flight termination altitude at altitudes below 70,000 feet (18). The payload descends very rapidly at higher altitudes due to the low atmospheric density. Consequently, wind drift above 70,000 feet contributes very little to the descent vector.

$$PDISP = \frac{ALT}{70000.} \cdot DISPP \qquad (3.1)$$

$$BDISP = \frac{ALT}{70000} \cdot DISPB \qquad (3.2)$$

4. Ascent Vector

The balloon location is defined by an altitude and a ground position relative to the launch point. An ascent vector is computed to each altitude level during ascent. This ascent vector is a function of the balloon climb rate and the wind profile in the ascent area. The ascent trajectory is computed in 1.Ø second increments until the desired altitude is reached.

$$INDX = \frac{H1}{ILEVEL} + 1 \qquad (4.1)$$

$$XBAL = XBAL + SPEEDA(INDX) \cdot COS\ (RDIRA(INDX)) \cdot TDEL \qquad (4.2)$$

$$YBAL = YBAL + SPEEDA(INDX) \cdot SIN\ (RDIRA(INDX)) \cdot TDEL \qquad (4.3)$$

$$RBAL = \sqrt{(XBAL)^2 + (YBAL)^2} \qquad (4.4)$$

$$AZBAL = TAN^{-1} \left(\frac{YBAL}{XBAL} \right) \qquad (4.5)$$

$$H1 = H1 + VASCNT \cdot TDEL \qquad (4.6)$$

5. Descent Vector

The nominal impact point is defined by a ground position relative to the flight termination point. A descent vector is computed from each altitude level to the earth's surface. Following flight termination, the payload/chute is separated from the balloon and both objects descend separately. The payload/chute descent vector is a function of the flight termination altitude, the wind profile in the descent area, and the payload/chute ballistic coefficient. It is assumed that the wind profile in the descent area is the same as in the ascent area. This is a valid assumption if the analysis is limited to the ascent phase.

Unlike the balloon climb rate which is nearly constant throughout the ascent, the descent rate varies considerably with altitude. As the payload/chute encounters a more dense atmosphere at lower altitude levels, the descent rate decreases. Figure 2 shows the forces acting on the payload/chute during descent.

The sum of these forces produces a payload/chute acceleration:

$$A = \frac{F}{AMASS} \tag{5.1}$$

where

$$F = WPLC - D \tag{5.2}$$

$$AMASS = \frac{WPLC}{G} \tag{5.3}$$

The drag force is a function of the atmospheric density at that altitude, the velocity of the payload/chute, and the parachute drag coefficient and reference area.

$$D = 0.5 \cdot RHO \cdot (V1)^2 \cdot CD \cdot S \tag{5.4}$$

The atmospheric density may be represented by a function of pressure and temperature which depends on altitude (21).

$$RHO = RHOZ \cdot \frac{P}{PZ} \cdot \frac{TZ}{T} \tag{5.5}$$

where

FORCES ACTING ON A PARACHUTE DURING DESCENT

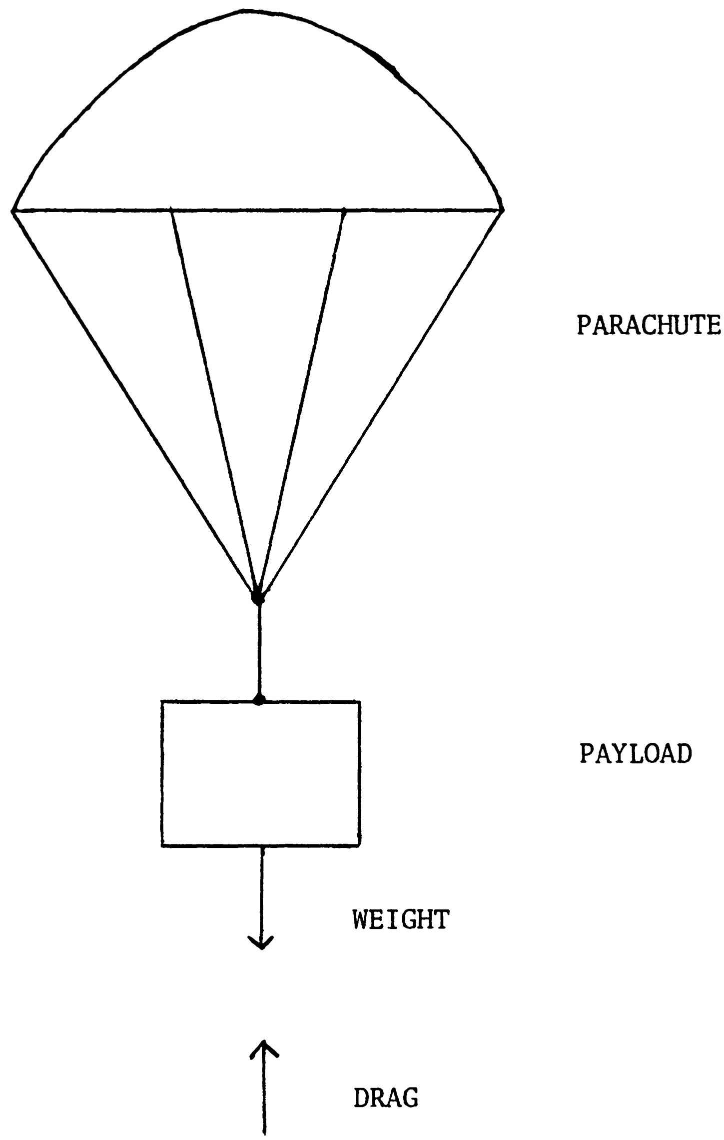


FIGURE 2

$$P = \left[1.91 - \frac{.01315\ H1}{1000.}\right]^{5.256} \quad (5.6)$$

$$T = 59.0 + 459.6 - \frac{H1}{280.} \quad (5.7)$$

for altitudes up to 36,500 feet

and where

$$P = 6.94\ e^{\left(1.69 - .0478 \frac{H1}{1000.}\right)} \quad (5.8)$$

$$T = 69.7 + 459.6 \quad (5.9)$$

for altitudes above 36,500 feet.

The descent trajectory is computed in 0.1 second intervals from the flight termination altitude to the surface.

$$V2 = V1 + A \cdot DELT \quad (5.10)$$

$$H2 = H1 - 0.5 \cdot (V1 + V2) \cdot DELT \quad (5.11)$$

$$INDX = \frac{H1}{ILEVEL} + 1 \quad (5.12)$$

$$XPLC = XPLC + SPEEDA(INDX) \cdot COS(RDIRA(INDX)) \cdot DELT \quad (5.13)$$

$$YPLC = YPLC + SPEEDA(INDX) \cdot SIN(RDIRA(INDX)) \cdot DELT \quad (5.14)$$

$$RPLC = \sqrt{(XPLC)^2 + (YPLC)^2} \quad (5.15)$$

$$AZPLC = TAN^{-1}\left(\frac{YPLC}{XPLC}\right) \quad (5.16)$$

6. Nominal Payload Impact Point

The nominal payload impact point is determined using the vector sum of the ascent vector to the point of failure and the descent vector from that point to the surface. This is graphically depicted in Figure 3.

ASCENT AND DESCENT VECTORS

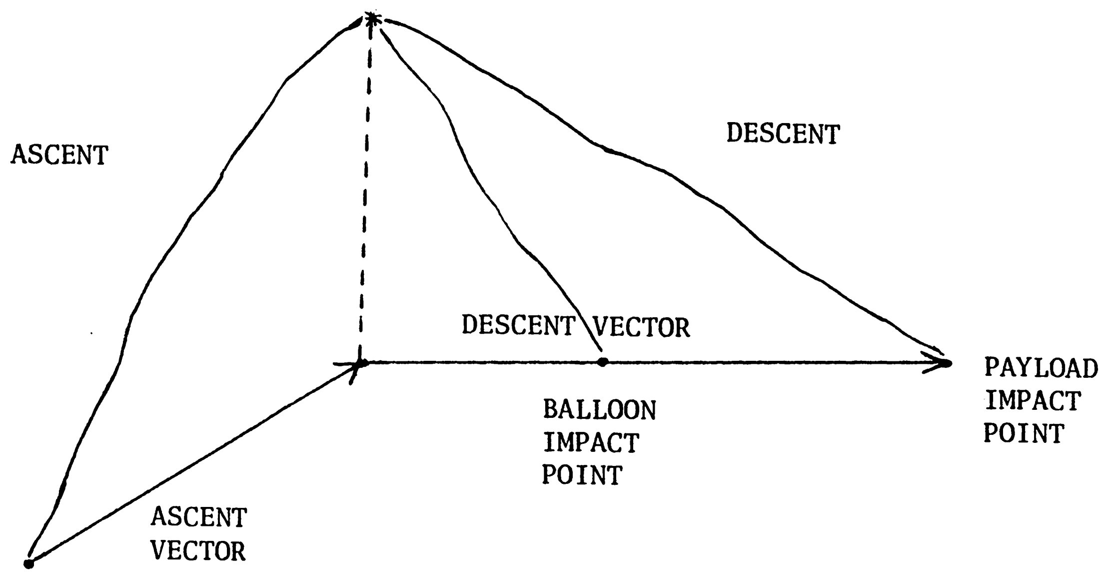


FIGURE 3

$$XPLI = XBAL + XPLC \qquad (6.1)$$

$$YPLI = YBAL + YPLC \qquad (6.2)$$

$$RPLI = \sqrt{(XPLI)^2 + (YPLI)^2} \qquad (6.3)$$

$$AZPLI = TAN^{-1}\left(\frac{YPLI}{XPLI}\right) \qquad (6.4)$$

The latitude and longitude of the nominal payload impact point are then calculated using this vector and the coordinates of the launch site.

7. Nominal Balloon Impact Point

The nominal balloon impact point is determined using the vector sum of the ascent vector to the point of failure and a modified descent vector from that point to the surface. The balloon can be expected to impact along the path of the payload descent vector but at a little less than half the distance of the payload. This is due to the higher balloon ballistic coefficient which results in a higher descent rate. The statistical mean for the ratio of the range of the balloon descent vector to that of the payload is 0.43 (32).

$$XBI = XBAL + BRATIO \cdot XPLC \qquad (7.1)$$

$$YBI = YBAL + BRATIO \cdot YPLC \qquad (7.2)$$

$$RBI = \sqrt{(XBI)^2 + (YBI)^2} \qquad (7.3)$$

$$AZBI = TAN^{-1}\left(\frac{YBI}{XBI}\right) \qquad (7.4)$$

The latitude and longitude of the nominal balloon impact point are then calculated in the same manner as the nominal payload impact point.

8. Probability of Failure

Thus far, the nominal payload and balloon impact points have been calculated assuming that a failure occurs at a certain altitude level. The next step is to calculate the probability of a failure occurring during that altitude interval.

$$FALT = P(F_h) \quad (8.1)$$

where

$$P(F_h) = P(F_h|F_a) \cdot P(F_a) \quad (8.2)$$

$$P(F_a) = P(F_a|F_m) \cdot P(F_m) \quad (8.3)$$

$$FALT = P(F_h|F_a) \cdot P(F_a|F_m) \cdot P(F_m) \quad (8.4)$$

where

F_m is Mission Failure

F_a is Ascent Phase Failure

F_h is Failure During This Altitude Interval

In the computer model,

$$P(F_m) = F \quad (8.5)$$

$$P(F_a|F_m) = FA \quad (8.6)$$

$$P(F_h|F_a) = FLEVEL(I) \cdot \frac{DELALT}{(ELEVEL(I) - BLEVEL(I))} \quad (8.7)$$

Thus, the probability of a failure occurring during that altitude interval is:

$$FALT = F \cdot FA \cdot FLEVEL(I) \cdot \frac{DELALT}{(ELEVEL(I) - BLEVEL(I))} \quad (8.8)$$

Historically, a .30 mission failure rate has been used for heavy payload balloon missions (5). Since 1985, there has been a major engineering effort to improve balloon reliability. The failure rate for balloons with the new Raven Astrofilm-E material is .09 (18).

Historically, approximately 40% of the balloon failures occur during the launch phase and are contained in the launch area. Another 40% of the mission failures occur during the ascent phase (5).

The distribution of failures during the ascent phase by altitude is not uniform. The balloon is more likely to fail when ascending through the low temperature region of the troposphere. Figure 4 shows the distribution of failures by altitude for heavy payload balloon missions (9)

A stress value is computed for each balloon flight. Historically, balloons with a stress value less than 2700 PSI have had a significantly lower failure rate than those with a stress value greater than 2700. The present engineering reliability program requires that the payload weight for a given balloon be limited to those weights that produce a stress value of 2700 PSI or less. The present .09 mission failure rate is valid provided the stress value is maintained below 2700.

9. Lethal Area

The lethal area is the "footprint" that an impacting object makes on the ground. A person standing within this footprint is likely to become a casualty. Since human beings are not point masses, it is accepted practice to add a one-foot buffer around

ALTITUDE DISTRIBUTION OF ASCENT FAILURES

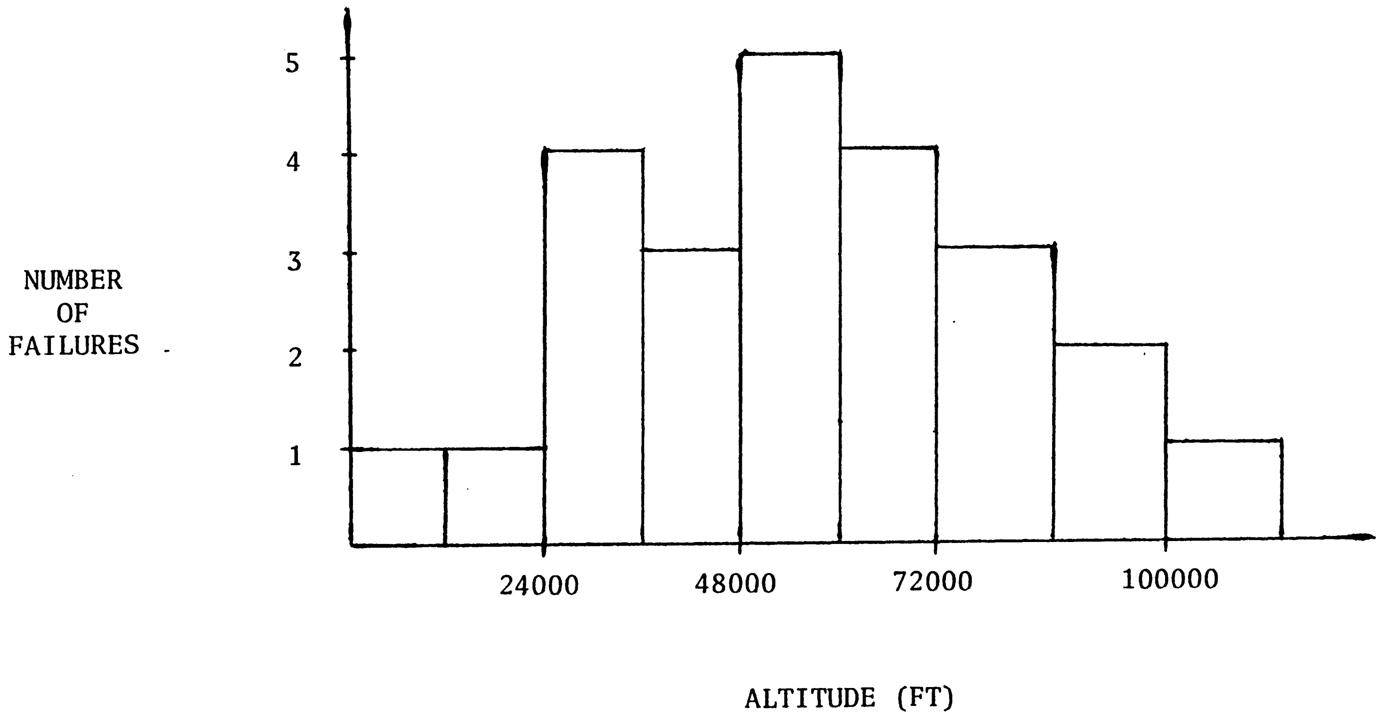


FIGURE 4

the footprint. This corresponds to a one-foot radius from the center point of an adult body (Figure 5).

The payload lethal area is the larger of the base area and the face area.

$$PLALB = (PLLEN + 2) \cdot (PLWID + 2) \quad (9.1)$$

$$PLALF = (PLLEN + 2) \cdot (PLHGT + 2) \quad (9.2)$$

$$PLAL = MAX\ (PLALB,\ PLALF) \quad (9.3)$$

Balloon impacts also pose a hazard to personnel. Large scientific balloons can weigh up to 4600 pounds. Balloons have a tendency to "ball up" during a descent and thus have a much higher weight to area ratio at impact than one might expect. Discussions with NSBF Operations personnel yielded approximate lethal areas for different balloon values and weights (5). Equations 9.4 and 9.5 were empirically developed to estimate balloon lethal area from balloon volume and weight.

$$BAL1 = 2.5 \sqrt{BALWT} \quad (9.4)$$

$$BAL2 = 55.0 \sqrt[3]{BALVOL} \quad (9.5)$$

The balloon lethal area used is the average of these two areas.

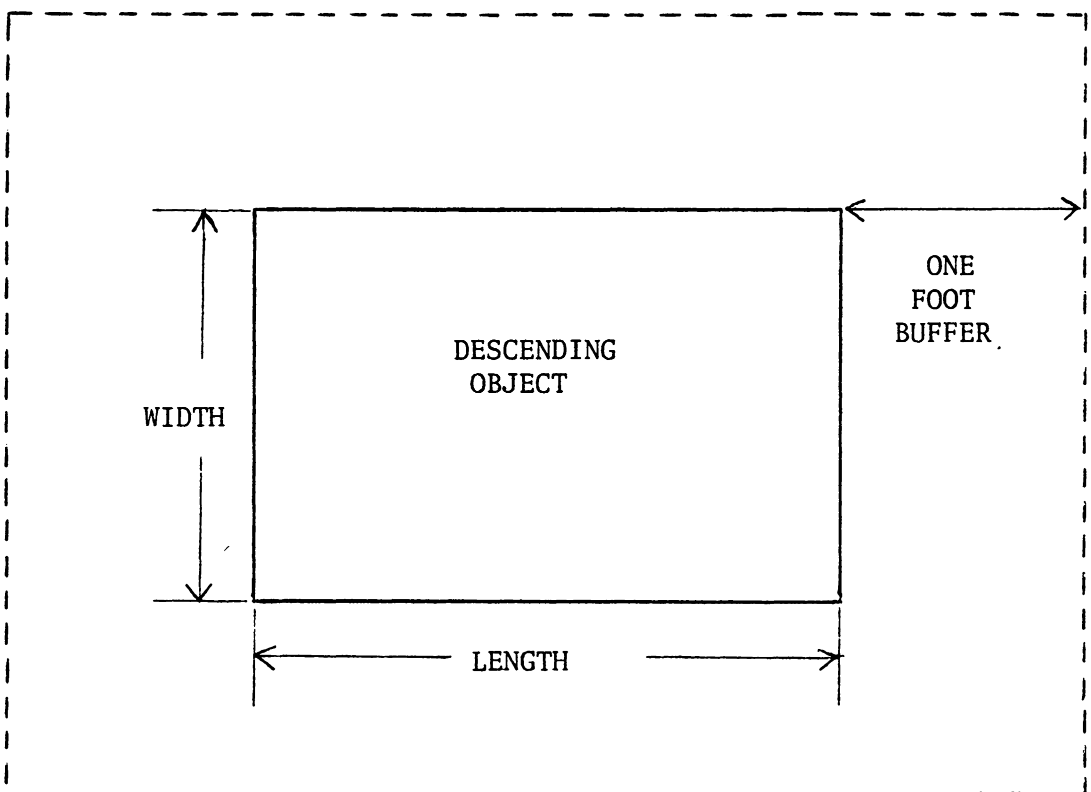
$$BALAL = \frac{BAL\ 1 + BAL\ 2}{2}$$

10. Risk Reduction Factor

Equation B.2 shows that the nominal casualty expectation risk is reduced by the risk reduction factor. For this model, the risk reduction factor is composed of three elements (5).

a. Surveillance - the tracking aircraft conducts aerial

LETHAL AREA



LETHAL AREA = (LENGTH + 2) (WIDTH + 2)

FIGURE 5

surveillance of the predicted descent corridor prior to flight termination. Figure 6 shows a diagram of the descent corridor including the payload and balloon impact areas. If there are towns or cities in or near the impact areas, another flight termination point can usually be selected. The surveillance factor represents the percentage of the remaining population that can be detected and avoided. The effectiveness of this procedure is diminished at night.

b. Pickling - during descent, the payload can be separated from the parachute by a command from the tracking aircraft. Figure 7 shows the effect of pickling on the payload impact point. Pickling may be performed if it appears that continued drift of the payload/chute will result in an impact in a populated area and pickling would result in an impact in a safe area.

The pickling factor represents the percentage of the remaining population that can be avoided. The effectiveness of this procedure is significantly diminished at night. Note that no reduction is applied to the balloon impact risk due to pickling since no control can be exercised over the balloon once the mission is terminated.

c. Protection - the protection afforded to people on the ground is a function of two factors: detectability and structural protection (5, 10).

DESCENT CORRIDOR AND IMPACT AREAS

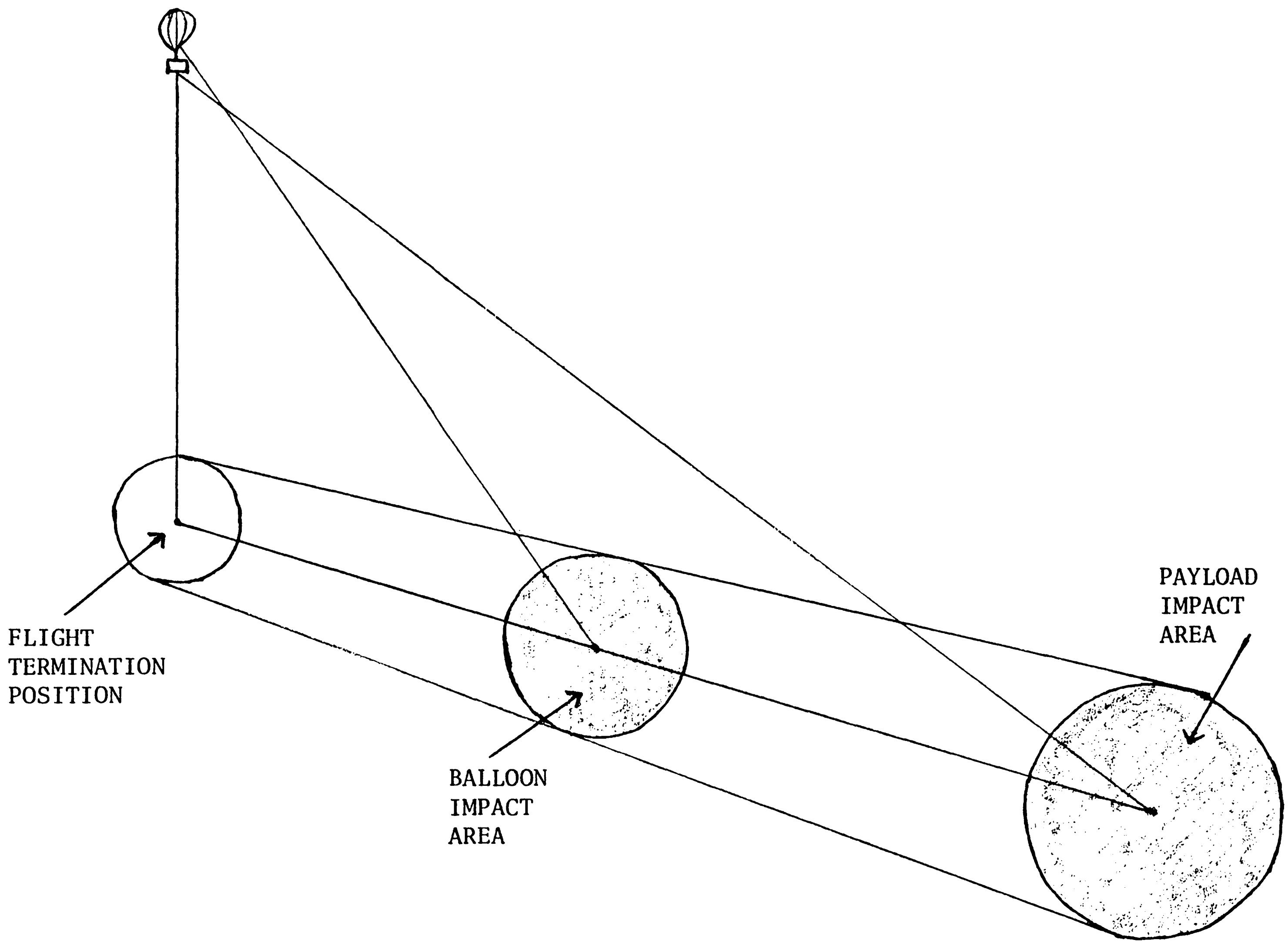


FIGURE 6

PICKLING

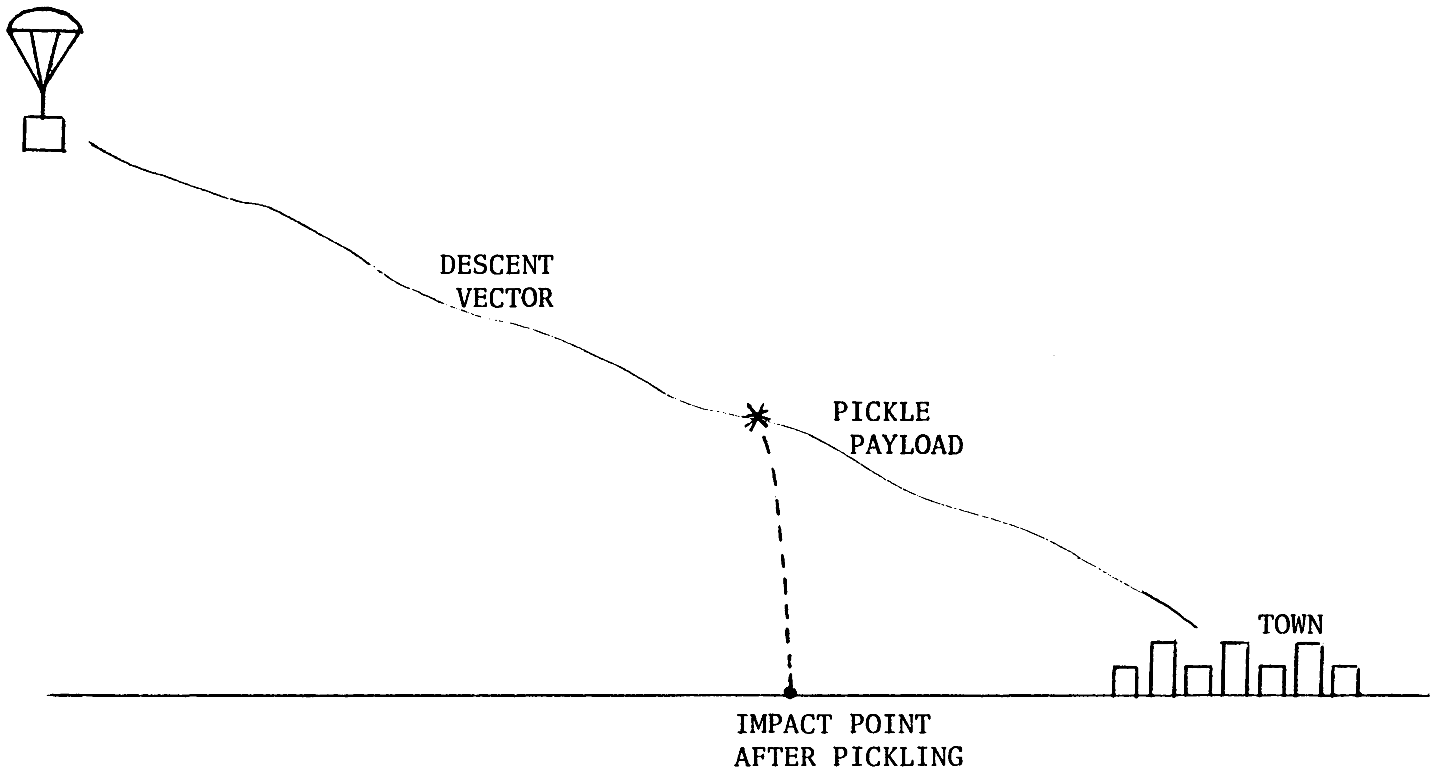


FIGURE 7

1. Detectability - people outdoors may detect the descending object and get out of the way. Figure 8 shows the location of people in rural areas and the likelihood of a person detecting a descending payload/chute or balloon. Note that the payload is equipped with a strobe light.

2. Structural Protection - people indoors may be protected by structures. Figure 9 shows the distribution of structure types in rural areas and the likelihood of a certain type of structure providing protection (5).

The detectability and structural protection factors are combined into one overall protection factor.

$$PPROD = 1 - (PCTPOD \cdot PDPLD + (1 - PCTPOD) \cdot SPPL) \quad (10.1)$$

$$PPRON = 1 - (PCTPON \cdot PDPLN + (1 - PCTPON) \cdot SPPL) \quad (10.2)$$

$$BPROD = 1 - (PCTPOD \cdot PDBD + (1 - PCTPOD) \cdot SPBAL) \quad (10.3)$$

$$BPRON = 1 - (PCTPON \cdot PDBN + (1 - PCTPON) \cdot SPBAL) \quad (10.4)$$

The risk reduction factor is the product of the surveillance, pickling, and protection factors. It is assumed, at this point, that each risk reduction step can be fully applied.

$$XPD = (1 - SURD) \cdot (1 - PICD) \cdot PPROD \quad (10.5)$$

$$XPN = (1 - SURN) \cdot (1 - PICN) \cdot PPRON \quad (10.6)$$

$$XBD = (1 - SURD) \cdot (1.00) \cdot BPROD \quad (10.7)$$

$$XBN = (1 - SURN) \cdot (1.00) \cdot BPRON \quad (10.8)$$

11. Controllability

Balloon failures range from slow leaks to catastrophic

LOCATION OF PEOPLE IN RURAL AREAS

	DAY	NIGHT
Outdoors	50%	5%
Indoors	50%	95%

DETECTABILITY OF DESCENDING PAYLOAD/CHUTE OR BALLOON

	DAY	NIGHT
Payload/chute	90%	90%
Balloon	80%	0%

FIGURE 8

DISTRIBUTION OF STRUCTURE TYPES IN RURAL AREAS

Multi-story	40%
Single-story	50%
Trailer or shack	10%

LIKELIHOOD OF STRUCTURE PROVIDING PROTECTION

	MULTI-STORY	SINGLE-STORY	TRAILER/SHACK
Heavy payload	0%	0%	0%
Non-heavy payload	25%	0%	0%
Heavy balloon	100%	100%	50%
Non-heavy balloon	100%	100%	75%

FIGURE 9

failures where flight termination is immediate. Controllability represents the degree of control that can be exercised over the payload/chute or the balloon following a failure. Balloon failures are classified as being one of three types depending on their controllability (5).

1. Completely controllable
2. Partially controllable
3. Uncontrollable

Completely controllable is treated as a planned impact with all risk reduction factors being fully applied. Partially controllable describes a wide range of descent velocities where the risk reduction steps can only be partially applied. The AMULT term in equations 11.1 - 11.4 represents the increased risk multiplier due to the decreased effectiveness of the risk reduction procedures. Uncontrollable is treated as a random impact without any surveillance or pickling risk reduction factors being applied. The payload is assumed to free fall; zero structural protection is assumed. The balloon descends in the usual manner; thus the balloon protection factor is retained.

<u>Payload Risk Reduction Factors:</u>

$$X = CNF \cdot XPD + PCNF \cdot XPD \cdot AMULT + UCNF \quad \text{(DAY)} \qquad (11.1)$$

$$X = CNF \cdot XPN + PCNF \cdot XPN \cdot AMULT + UCNF \quad \text{(NIGHT)} \qquad (11.2)$$

<u>Balloon Risk Reduction Factors:</u>

$$X = CNF \cdot XBD + PCNF \cdot XBD \cdot AMULT + UCNF \quad \text{(DAY)} \qquad (11.3)$$

$$X = CNF \cdot XBN + PCNF \cdot XBN \cdot AMULT + UCNF \quad \text{(NIGHT)} \quad (11.4)$$

12. Population Density

Thus far, the probability of impacting in a certain area has been calculated. The next step is to calculate the population density in the impact area. Population is not uniformly distributed over the entire ascent area; a large percentage of the population is clustered in identifiable towns and cities (30). A data base containing the town and city locations and their populations has been compiled (2). An edited version of this data base for the ascent area is included in Appendix 3. The remainder of the population in the ascent area is assumed to be uniformly distributed. The casualty expectation is calculated for each of the towns in the impact area and for the residual population.

The population is increasing in the operational area. The population in the state of Texas has increased 18% since 1980 (29). The actual distribution of this population will not be known until after the 1990 census. It is assumed that this population growth is uniformly distributed throughout the ascent area. The population growth factor is included in equations 14.3 and 14.6.

13. Town Impact Probability

The probability of impacting in a town depends on three factors (7).

1. The size of the town.

2. The distance of the town from the nominal impact point.

3. The dispersion of the impacting object.

Graphically, the probability of impacting in town A is the probability of impacting in the shaded strip times the area ratio (Figure 10).

$$P(I_t) = P(I_t | I_s) \cdot P(I_s) \qquad (13.1)$$

where

I_t = TOWN IMPACT

I_s = STRIP IMPACT

$$P(I_t) = \frac{\text{AREA A}}{\text{AREA STRIP}} \cdot (P_{\text{sigma2}} - P_{\text{sigma1}}) \qquad (13.2)$$

The distance between the nominal impact point and the town is calculated using the coordinates of the town and the nominal impact point.

The sigma distances of the payload and balloon impact points from the town can then be calculated.

$$\text{SIGPL} = \frac{\text{DPLT}}{\text{PDISP}} \qquad (13.3)$$

$$\text{SIGB} = \frac{\text{DBT}}{\text{BDISP}} \qquad (13.4)$$

An empirical estimate of the town size is then computed.

$$\text{TWNSZ} = \sqrt{\frac{\text{TOWNPOP}}{1000.}} \qquad (13.5)$$

The exact area of the town is not significant since the town area term will cancel out in the casualty expectation equation. The probability of the payload or the balloon

PROBABILITY OF IMPACTING IN A TOWN

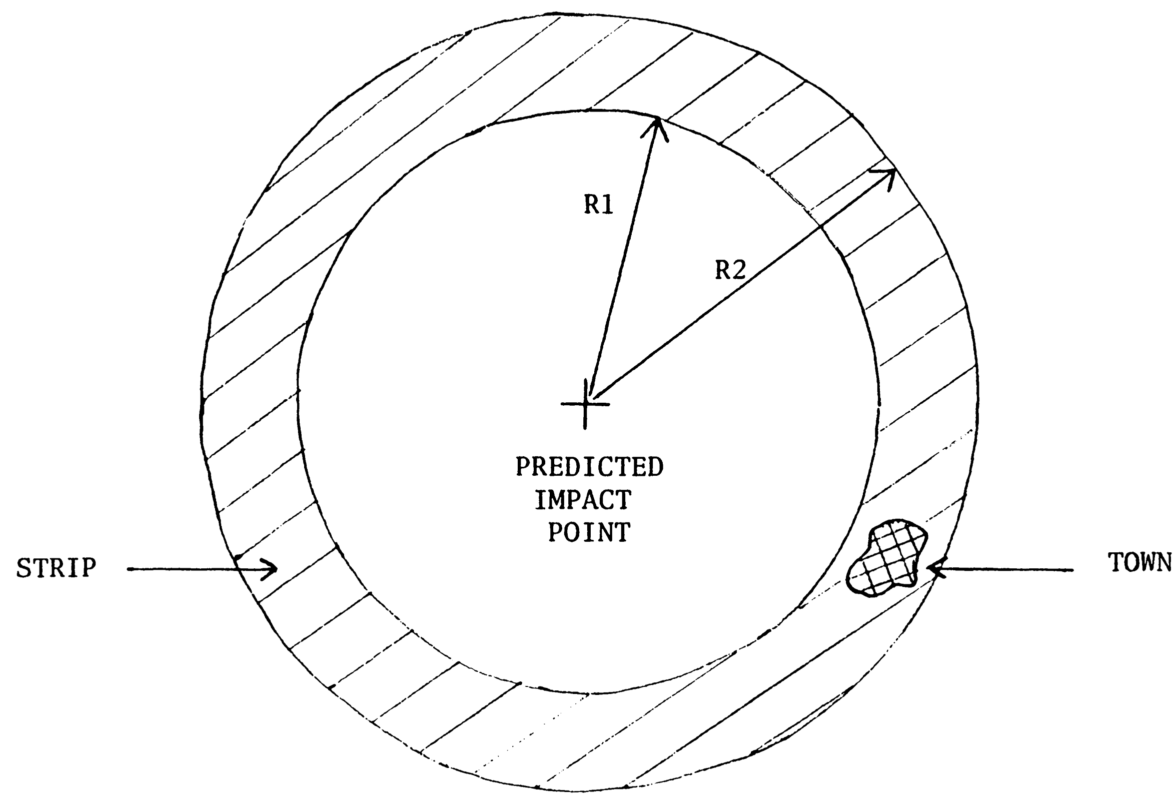


FIGURE 10

impacting in the town calculation is straightforward at this point.

PAYLOAD

$$SIG2 = SIGPL + .10 \quad (13.6)$$

$$SIG1 = SIGPL - .10 \quad (13.7)$$

$$P2 = 1 - e^{-1/2(SIG2)^2} \quad (13.8)$$

$$P1 = 1 - e^{-1/2(SIG1)^2} \quad (13.9)$$

$$R2 = DPLT + .10\ PDISP \quad (13.10)$$

$$R1 = DPLT - .10\ PDISP \quad (13.11)$$

$$TIPPL = (P2 - P1) \cdot \frac{TWNSZ}{\pi \left[(R2)^2 - (R1)^2\right]} \quad (13.12)$$

BALLOON

$$SIG2 = SIGB + .10 \quad (13.13)$$

$$SIG1 = SIGB - .10 \quad (13.14)$$

$$P2 = 1 - e^{-1/2(SIG2)^2} \quad (13.15)$$

$$P1 = 1 - e^{-1/2(SIG1)^2} \quad (13.16)$$

$$R2 = DBT + .10\ BDISP \quad (13.17)$$

$$R1 = DBT - .10\ BDISP \quad (13.18)$$

$$TIPBAL = (P2 - P1) \frac{TWNSZ}{\pi \left[(R2)^2 - (R1)^2\right]} \quad (13.19)$$

14. Town Casualty Expectation

Adding the risk reduction factor to the basic casualty expectation equation (B.1) produces the following risk equation.

$$CE = P_I \cdot P_D \cdot A_L \cdot X \qquad (14.1)$$

The risk reduction factors have been previously calculated in equations 11.1 - 11.4. The P_I, P_D, and A_L terms for the payload and the balloon are computed in equations 14.2 - 14.7.

PAYLOAD

$$P_I = FALT \cdot TIPPL \qquad (14.2)$$

$$P_D = \frac{TOWNPOP \cdot POPADJ}{TWNSZ} \qquad (14.3)$$

$$A_L = PLAL \qquad (14.4)$$

BALLOON

$$P_I = FALT \cdot TIPBAL \qquad (14.5)$$

$$P_D = \frac{TOWNPOP \cdot POPADJ}{TWNSZ} \qquad (14.6)$$

$$A_L = BALAL \qquad (14.7)$$

The total casualty expectation for a given town is the sum of the casualty expectation due to the payload impact and the casualty expectation due to the balloon impact.

$$TOWNCED = CEPL_{day} + CEBAL_{day} \quad (DAY) \qquad (14.8)$$

$$TOWNCEN = CEPL_{night} + CEBAL_{night} \quad (NIGHT) \qquad (14.9)$$

15. Residual Casualty Expectation

Since the residual population is assumed to be uniformly distributed over the ascent area, the residual population density will be constant throughout the ascent.

$$P_D = \frac{(TPOP - POPSUM)\ (POPADJ)}{TAREA} \qquad (15.1)$$

Unlike the town impact probability which changes at each point during the ascent, the residual impact probability remains constant at each altitude interval. Thus, it matters only whether the balloon fails; where it fails during ascent is not significant for this calculation.

$$P_I = F \cdot FA\,(1 - TIP) \qquad (15.2)$$

where TIP is the cumulative town impact probability for the ascent phase. Since TIP is a very small number, 1- TIP can be approximated by 1.Ø. The impact probabilities for the payload and the balloon are the same. The lethal areas and risk reduction factors are the same as for the town casualty expectation calculations. The total casualty expectation for the residual population is the sum of the casualty expectation due to the payload impact and the casualty expectation due to the balloon impact.

$$CERESD = CEPL_{day} + CEBAL_{day} \qquad (DAY) \qquad (15.3)$$

$$CERESN = CEPL_{night} + CEBAL_{night} \qquad (NIGHT) \qquad (15.4)$$

16. Total Casualty Expectation

The total casualty expectation for the ascent phase is calculated by summing the town casualty expectation over all altitude levels and adding the residual casualty expectation.

$$CEDAY = \sum_{i=1}^{NTOWN} \sum_{j=1}^{M} TOWNCED_{ij} + CERESD \qquad (DAY) \qquad (16.1)$$

$$CENIGHT = \sum_{i=1}^{NTOWN} \sum_{j=1}^{M} TOWNCEN_{ij} + CERESN \qquad (NIGHT) \qquad (16.2)$$

where

NTOWN = number of towns

M = number of altitude levels

17. Maximum Town Risk

The maximum risk to which any one town is subjected is also of interest. The casualty expectation risk for each town is integrated over all of the altitude levels for both day and night flights. The maximum risk to which any one town is subjected is determined by finding the largest risk.

CETMAX1 = MAX(TWNCEDS, TWNCENS) (17.1)

IV. RESULTS

A sample balloon ascent was run to demonstrate the model. A 27.0 million cubic feet balloon weighing 3000 pounds was launched from Palestine, Texas, during the daytime. The balloon climb rate was 900 feet per minute and the float altitude was 110,000 feet. The payload weighed 3000 pounds and its dimensions were 6.0 feet by 6.0 feet with a height of 4.0 feet. The parachute had a drag coefficient of 0.75 and a reference area of 7854.0 square feet. The 1-sigma payload and balloon dispersion were 5.54 NM and 5.57 NM respectively. The wind profile in the ascent area was as follows:

ALTITUDE (FT)	DIRECTION (DEG)	VELOCITY (FT/SEC)
0 - 10,000	270.0	10.0
10,000 - 20,000	270.0	20.0
20,000 - 30,000	270.0	35.0
30,000 - 40,000	270.0	60.0
40,000 - 50,000	270.0	50.0
50,000 - 60,000	270.0	40.0
60,000 - 70,000	270.0	25.0
70,000 - 80,000	270.0	20.0
80,000 - 90,000	270.0	25.0
90,000 - 100,000	270.0	25.0
100,000 - 110,000	270.0	30.0

The ascent phase risk for this particular mission is summarized in the following table.

TOWN	CASUALTY EXPECTATION (x 10^{-6})
Palestine	0.63
Rusk	0.32
Jacksonville	0.11
Alto	0.02
All other cities	0.02
Total City	1.10
Residual	0.30
Total	1.40

A complete listing of the program inputs and outputs is included in Appendix 4.

The ascent phase risk for this particular ascent trajectory exceeds the commonly accepted risk level of 1.0 x 10^{-6}. This is not surprising since the ascent trajectory overflys the city of Palestine which is located approximately 2.0 NM east of the launch site. Over half of the ascent phase risk is incurred by the city of Palestine. Rusk is about 25 NM east of Palestine near the point of maximum balloon failure probability. The ascent phase risk incurred for a nighttime launch would be 2.59 x 10^{-6}. This is higher than the daytime risk because the risk reduction procedures cannot be performed as effectively at night.

V. SUMMARY

A mathematical model is defined to predict the casualty expectation risk during the ascent phase of a balloon mission. The model can be run for different payload sizes and balloon volumes, and wind profiles in the ascent area. The effect of varying balloon failure rates and the effectiveness of risk reduction steps on mission risk can be determined. A sample program output for one particular balloon mission and wind profile is included. Operational constraints, such as permissible ascent vectors or the time of the day that the operation is conducted, could be imposed by the responsible safety personnel based on the mission risk matrix. The results of this model can be used to advise management of the risk level during the ascent phase of a balloon mission.

In addition to its use as a planning tool, this model could be run in "real time" to calculate the risk on the day of launch. The predicted risk could be compared to the commonly accepted risk value to determine whether the risk associated with this particular ascent trajectory is acceptable. This model could also be used for other balloon launch sites around the world. The only additional information required would be a population data base for that launch area and local weather data.

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APPENDIX 1

COMPUTER MODEL NOMENCLATURE

A	-	acceleration of payload/chute during descent
ALT	-	altitude of balloon during ascent
AMASS	-	mass of payload/chute
AMULT	-	risk multiplier for a partially controllable balloon
AZBAL	-	balloon ascent azimuth
AZBI	-	balloon impact azimuth
AZPLC	-	payload descent azimuth
AZPLI	-	payload impact azimuth
BALAL	-	balloon lethal area
BALVOL	-	balloon volume
BALWT	-	balloon weight
BAL1	-	balloon lethal area (based on weight)
BAL2	-	balloon lethal area (based on volume)
BDISP	-	1-sigma balloon impact dispersion ratioed for altitude
BLAT	-	balloon impact latitude
BLEVEL	-	beginning altitude of class
BLONG	-	balloon impact longitude
BPROD	-	daytime balloon protection factor
BPRON	-	nighttime balloon protection factor
BRATIO	-	mean ratio of balloon descent vector range to payload descent vector range
BRPLC	-	balloon descent vector range
C	-	conversion factor (5280 feet per mile)
CD	-	chute drag coefficient
CEBAL	-	balloon casualty expectation
CEDAY	-	total casualty expectation (day)
CENIGHT	-	total casualty expectation (night)
CEPL	-	payload casualty expectation
CERESD	-	residual casualty expectation (day)
CERESN	-	residual casualty expectation (night)
CETMAX1	-	maximum town casualty expectation
CETWND	-	total town casualty expectation (day)
CETWNN	-	total town casualty expectation (night)
CNF	-	percentage of failures resulting in a completely controllable balloon
D	-	drag force acting on payload/chute during descent
DBT	-	distance from balloon impact to town
DELALT	-	altitude increment during ascent
DELT	-	delta time increment used in subroutine DESCNT
DISPB	-	1-sigma balloon dispersion
DISPP	-	1-sigma payload/chute dispersion

DPLT	-	distance from payload impact to town
ELEVEL	-	ending altitude of class
F	-	mission failure rate
FA	-	percentage of mission failures occurring during ascent
FALT	-	probability of a failure in altitude class
FLEVEL	-	percentage of ascent failures occurring in that altitude class
G	-	gravitational acceleration
HASCNT	-	altitude to which the ascent vector is computed
HDSCNT	-	altitude from which the descent vector is computed
HFLOAT	-	float altitude
H1	-	current altitude in subroutine DESCNT
H2	-	new altitude in subroutine DESCNT Δt seconds later
ILEVEL	-	depth of each wind level
INDX	-	altitude index
KLEVEL	-	number of altitude classes
LAT	-	launch site latitude
LONG	-	launch site longitude
NAMSCI	-	mission scientist
NAMSIT	-	launch site
NDATE	-	planned launch date
NLEVEL	-	number of wind levels
NTIME	-	time of day of the launch (day or night)
P	-	atmospheric pressure
PCNF	-	percentage of failures resulting in a partially controllable balloon
PCTPOD	-	percentage of population outdoors (daytime)
PCTPON	-	percentage of population outdoors (nighttime)
PDBD	-	probability of detecting and avoiding balloon (daytime)
PDBN	-	probability of detecting and avoiding balloon (nighttime)
PDENR	-	residual population density
PDISP	-	1-sigma payload impact dispersion ratioed for altitude
PDPLD	-	probability of detecting and avoiding payload (daytime)
PDPLN	-	probability of detecting and avoiding payload (nighttime)
PICD	-	pickling factor (daytime)
PICN	-	pickling factor (nighttime)
PLAL	-	payload lethal area
PLALB	-	lethal area of the payload base
PLALF	-	lethal area of the payload face
PLAT	-	payload impact latitude
PLHGT	-	payload height

PLLEN	-	payload length
PLONG	-	payload impact longitude
PLRAD	-	payload radius
PLWID	-	payload width
POPADJ	-	population growth factor
POPDEN	-	population density of town
POPSUM	-	total population of towns in the ascent area
PPROD	-	daytime payload protection factor
PPRON	-	nighttime payload protection factor
PZ	-	sea level atmospheric pressure
RBAL	-	balloon ascent range
RBI	-	balloon impact range
RDIRA	-	wind direction
RHO	-	atmospheric density
RHOZ	-	sea level atmospheric density
RPLC	-	payload descent range
RPLI	-	payload impact range
S	-	chute reference area
SIGB	-	sigma distance from balloon impact to town
SIGPL	-	sigma distance from payload impact to town
SPBAL	-	balloon structural protection factor
SPEEDA	-	wind speed
SPPL	-	payload structural protection factor
SURD	-	daytime surveillance factor
SURN	-	nighttime surveillance factor
T	-	atmospheric temperature
TAREA	-	total area of ascent area
TBAL	-	balloon ascent time
TDEL	-	delta time increment used in subroutine ASCENT
TIPBAL	-	balloon town impact probability
TIPPL	-	payload town impact probability
TOWNCED	-	component of daytime town casualty expectation for one altitude level
TOWNCEN	-	component of nighttime town casualty expectation for one altitude level
TOWNPOP	-	town population
TPLC	-	payload descent time
TPOP	-	total population in ascent area
TWNCEDS	-	cumulative daytime casualty expectation for a town
TWNCENS	-	cumulative nighttime casualty expectation for a town
TWNSZ	-	town area
TZ	-	sea level atmospheric temperature
UCNF	-	percentage of failures resulting in an uncontrolled free-fall
VASCNT	-	balloon climb rate

VDSCNT	-	vertical velocity at balloon ascent termination
V1	-	current vertical velocity in subroutine DESCNT
V2	-	new vertical velocity in subroutine DESCNT Δt seconds later
WPLC	-	weight of payload/chute
XBAL	-	x component of balloon ascent range
XBD	-	daytime balloon risk reduction factor
XBI	-	x component of balloon impact range
XBN	-	nighttime balloon risk reduction factor
XPD	-	daytime payload risk reduction factor
XPLC	-	x component of payload descent range
XPLI	-	x component of payload impact range
XPN	-	nighttime payload risk reduction factor
YBAL	-	y component of balloon ascent range
YBI	-	y component of balloon impact range
YPLC	-	y component of payload descent range
YPLI	-	y component of payload impact range

APPENDIX 2

```
C      BALLOON ASCENT RISK MODEL
C
C      WRITTEN BY:
C        ROB BEYMA
C        MARCH 1988
C
C      INPUTS:
C        LINE-1
C          NAMSCI...MISSION SCIENTIST
C          NDATE....PLANNED LAUNCH DATE
C          NAMSIT...LAUNCH SITE
C          NTIME....TIME OF DAY OF LAUNCH (DAY OR NIGHT)
C        LINE-2
C          LAT......LAUNCH SITE LATITUDE
C          LONG.....LAUNCH SITE LONGITUDE
C        LINE-3
C          BALVOL...BALLOON VOLUME (MILLIONS CUBIC FEET)
C          BALWT....BALLOON WEIGHT (LBS)
C          PLLEN....PAYLOAD LENGTH (FT)
C          PLWID....PAYLOAD WIDTH (FT)
C          PLHGT....PAYLOAD HEIGHT (FT)
C          PLRAD....PAYLOAD RADIUS (FT)
C        LINE-4
C          HFLOAT...FLOAT ALTITUDE (FT)
C          VASCNT...BALLOON CLIMB RATE (FT/SEC)
C        LINE-5
C          WPLC.....WEIGHT OF PAYLOAD/CHUTE (LBS)
C          CD.......DRAG COEFFICIENT OF PAYLOAD/CHUTE
C          S........REFERENCE AREA OF CHUTE (FT2)
C          DISPP....1-SIGMA PAYLOAD/CHUTE DISPERSION (NM)
C          BRATIO...MEAN BALLOON/PAYLOAD IMPACT RANGE RATIO
C          DISPB....1-SIGMA BALLOON DISPERSION (NM)
C        LINE-6
C          NLEVEL...NUMBER OF WIND LEVELS
C          ILEVEL...DEPTH OF EACH WIND LEVEL (FT)
C        LINE-7 (*)
C          RDIRA....WIND DIRECTION (DEG)
C          SPEEDA...WIND SPEED (FT/SEC)
C        LINE-8
C          F........MISSION FAILURE RATE
C          FA.......PERCENTAGE OF MISSION FAILURES OCCURING DURING ASCENT
C          KLEVEL...NUMBER OF ALTITUDE CLASSES FOR FAILURE DISTRIBUTION
C        LINE-9 (*)
C          BLEVEL...BEGINNING ALTITUDE OF CLASS

C          ELEVEL...ENDING ALTITUDE OF CLASS
C          FLEVEL...PERCENTAGE OF ASCENT FAILURES OCCURING IN CLASS
C        LINE-10
C          TPOP.....TOTAL POPULATION IN ASCENT AREA
C          TAREA....TOTAL AREA OF ASCENT AREA (MI2)
C          POPADJ...POPULATION GROWTH FACTOR SINCE 1980 CENSUS
C        LINE-11
```

```
C          CNF......COMPLETELY CONTROLLABLE FACTOR
C          PCNF.....PARTIALLY CONTROLLABLE FACTOR
C          UCNF.....UNCONTROLLABLE FACTOR
C          AMULT....RISK MULTIPLIER FOR PARTIAL CONTROLLABILITY
C        LINE-12
C          SURD.....SURVEILLANCE FACTOR (DAY)
C          SURN.....SURVEILLANCE FACTOR (NIGHT)
C        LINE-13
C          PICD.....PICKLING FACTOR (DAY)
C          PICN.....PICKLING FACTOR (NIGHT)
C        LINE-14
C          PCTPOD...PERCENTAGE POPULATION OUTDOORS (DAY)
C          PCTPON...PERCENTAGE POPULATION OUTDOORS (NIGHT)
C        LINE-15
C          PDPLD....PROBABILITY DETECT AND AVOID PAYLOAD (DAY)
C          PDPLN....PROBABILITY DETECT AND AVOID PAYLOAD (NIGHT)
C          PDBD.....PROBABILITY DETECT AND AVOID BALLOON (DAY)
C          PDBN.....PROBABILITY DETECT AND AVOID BALLOON (NIGHT)
C        LINE-16
C          SPPL.....STRUCTURAL PROTECTION FACTOR (PAYLOAD)
C          SPBAL....STRUCTURAL PROTECTION FACTOR (BALLOON)
C
C      OUTPUTS:
C        NAMCNTY...COUNTY NAME
C        NAMTOWN...TOWN NAME
C        TOWNCED...TOWN CASUALTY EXPECTATION (DAY)
C        TOWNCEN...TOWN CASUALTY EXPECTATION (NIGHT)
C        CERESD....RESIDUAL CASUALTY EXPECTATION (DAY)
C        CERESN....RESIDUAL CASUALTY EXPECTATION (NIGHT)
C        CEDAY.....TOTAL CASUALTY EXPECTATION (DAY)
C        CENIGHT...TOTAL CASUALTY EXPECTATION (NIGHT)
C
C      FILES USED:
C        1   INPUTS (BARM.D)
C        2   POPULATION DATA BASE (BARM.T)
C        6   OUTPUTS (BARM.P)
C
C      SUBROUTINES USED:
C        ASCENT...ASCENT VECTOR PREDICTION
C        DESCNT...DESCENT VECTOR PREDICTION
C        LETHAR...LETHAL AREAS CALCULATION
C        OBLATE... CALCULATE LATITUDE AND LONGITUDE OF A POINT ON
C                  THE EARTH'S SURFACE, OR CALCULATE THE DISTANCE
C                  BETWEEN TWO POINTS
C
C
C      INITIALIZATION
C
       DOUBLE PRECISION  RP,RE,GC1,GC2,AZ,R,AG,EC,RL,V,GD1,L1,GD2,L2
       REAL LAT,LONG
       DIMENSION BLEVEL(10),ELEVEL(10),FLEVEL(10),
```

```
     *  NAMTOWN(200),NAMCNTY(200),TOWNLAT(200),TOWNLON(200),
     *  TOWNPOP(200),TOWNCED(200),TOWNCEN(200),TWNCEDS(200),
     *  TWNCENS(200),IAST(200)
      CHARACTER*10 NAMSCI
      CHARACTER*12 NAMSIT,NDATE
      CHARACTER*16 NAMCNTY
      CHARACTER*20 NAMTOWN
      CHARACTER*5  NTIME
C
      COMMON /AAA/RP,RE,GC1,GC2,AZ,R,AG,EC,RL,N,K,V,M/BB/GD1,L1,GD2,L2
      COMMON /B/ PLLEN,PLWID,PLHGT,PLRAD,BALVOL,BALWT,PLALB,PLALF,BALAL
      COMMON /BA/ HASCNT,VASCNT,TBAL,XBAL,YBAL,RBAL,AZBAL,TDEL
      COMMON /PD/ HDSCNT,VDSCNT,TPLC,XPLC,YPLC,RPLC,AZPLC,DELT,
     * WPLC,CD,S
      COMMON /WW/ NLEVEL,ILEVEL,RDIRA(15),SPEEDA(15),IPRNT
C
      DELT=0.10
      TDEL=1.00
      ALT=0.0
      DELALT=2000.
      PIE=3.141592654
      DEGPRAD=57.29577951
      FTPNM=6076.1155
      CETWND=0.0
      CETWNN=0.0
      NTOWN=0
      POPSUM=0.0
      IMAX=1
      IPRNT=0
      CETMAX1=0.0
C
      DO 10 I=1,200
      TWNCEDS(I)=0.0
      TWNCENS(I)=0.0
   10 IAST(I)=1H
C
C     READ AND PRINT INPUTS
C
      READ(1,*) NAMSCI,NDATE,NAMSIT,NTIME
      READ(1,*) LAT,LONG
      READ(1,*) BALVOL,BALWT,PLLEN,PLWID,PLHGT,PLRAD
      READ(1,*) HFLOAT,VASCNT
      READ(1,*) WPLC,CD,S,DISPP,BRATIO,DISPB
      READ(1,*) NLEVEL,ILEVEL
      DO 20 I=1,NLEVEL
      READ(1,*) RDIRA(I),SPEEDA(I)
   20 CONTINUE
      READ(1,*) F,FA,KLEVEL
      DO 30 I=1,KLEVEL
      READ(1,*) BLEVEL(I),ELEVEL(I),FLEVEL(I)
   30 CONTINUE
```

```
      READ(1,*) TPOP,TAREA,POPADJ
      READ(1,*) CNF,PCNF,UCNF,AMULT
      READ(1,*) SURD,SURN
      READ(1,*) PICD,PICN
      READ(1,*) PCTPOD,PCTPON
      READ(1,*) PDPLD,PDPLN,PDBD,PDBN
      READ(1,*) SPPL,SPBAL
C
      WRITE(6,40)
   40 FORMAT(1H1,2X,// ,15X,14H*** INPUTS ***)
      WRITE(6,50) NAMSCI,NDATE,NAMSIT,NTIME
   50 FORMAT(2X,// ,5X,12HSCIENTIST   ,1X,A10,/,
     *              5X,12HLAUNCH DATE ,1X,A12,/,
     *              5X,12HLAUNCH SITE ,1X,A12,/,
     *              5X,12HTIME OF DAY ,1X,A5)
      WRITE(6,60) LAT,LONG
   60 FORMAT(2X,/,5X,10HLATITUDE  ,1X,F7.3,/,
     *            5X,10HLONGITUDE ,F8.3)
      WRITE(6,70) BALVOL,BALWT,PLLEN,PLWID,PLHGT,PLRAD
   70 FORMAT(2X,/,5X,34HBALLOON VOLUME (MILLIONS CUBIC FT) ,4X,F5.2,/,
     *            5X,21HBALLOON WEIGHT (LBS) ,15X,F5.0,/,
     *            5X,20HPAYLOAD LENGTH (FT) ,18X,F5.2,/,
     *            5X,19HPAYLOAD WIDTH (FT) ,19X,F5.2,/,
     *            5X,20HPAYLOAD HEIGHT (FT) ,18X,F5.2,/,
     *            5X,20HPAYLOAD RADIUS (FT) ,18X,F5.2)
      WRITE(6,80) HFLOAT,VASCNT
   80 FORMAT(2X,/,5X,20HFLOAT ALTITUDE (FT) ,F7.0,/,
     *            5X,20HCLIMB RATE (FT/SEC) ,4X,F5.2)
C
      WRITE(6,90) WPLC,CD,S,DISPP,DISPB,BRATIO
   90 FORMAT(2X,/,5X,27HPAYLOAD/CHUTE WEIGHT (LBS) ,4X,F5.0,/,
     *            5X,23HCHUTE DRAG COEFFICIENT ,11X,F4.2,/,
     *            5X,27HCHUTE REFERENCE AREA (FT2) ,4X,F7.2,/,
     *            5X,32H1-SIGMA PAYLOAD DISPERSION (NM) ,2X,F4.2,/,
     *            5X,32H1-SIGMA BALLOON DISPERSION (NM) ,2X,F4.2,//,
     *            5X,39HMEAN BALLOON/PAYLOAD IMPACT RANGE RATIO,3X,F4.2)
      WRITE(6,100) NLEVEL, ILEVEL
  100 FORMAT(2X,/,5X,22HNUMBER OF WIND LEVELS ,4X,I2,/,
     *            5X,26HDEPTH OF WIND LEVELS (FT) ,I5,/)
      DO 120 I=1,NLEVEL
      I1=(I-1)*ILEVEL
      I2=I*ILEVEL
      WRITE(6,110) I1,I2,RDIRA(I),SPEEDA(I)
  110 FORMAT(5X,I6,3H - ,I6,3H FT,5X,F5.1,4H DEG,3X,F5.1,7H FT/SEC)
  120 CONTINUE
      WRITE(6,130) F,FA,KLEVEL
  130 FORMAT(2X,/,5X,21HMISSION FAILURE RATE ,13X,F4.2,/,
     *  5X,34HPERCENTAGE FAILURES DURING ASCENT ,F4.2,/,
     *  5X,27HNUMBER OF ALTITUDE CLASSES ,9X,I2,//,
     *  5X,33HALTITUDE DISTRIBUTION OF FAILURES,/)
```

```
C
      DO 150 I=1,KLEVEL
      WRITE(6,140) BLEVEL(I),ELEVEL(I),FLEVEL(I)
  140 FORMAT(5X,F7.0,3H - ,F7.0,3H FT,5X,F5.3)
  150 CONTINUE
      WRITE(6,160) TPOP,TAREA,POPADJ
  160 FORMAT(2X,/,5X,29HTOTAL POPULATION ASCENT AREA ,1X,F7.0,/,
     *            5X,29HTOTAL AREA ASCENT AREA (MI2) ,3X,F6.1,/,
     *            5X,25HPOPULATION GROWTH FACTOR ,10X,F4.2)
      WRITE(6,170) CNF,PCNF,UCNF,AMULT
  170 FORMAT(2X,/,5X,24HCOMPLETELY CONTROLLABLE ,F4.2,/,
     *            5X,23HPARTIALLY CONTROLLABLE ,1X,F4.2,/,
     *            5X,15HUNCONTROLLABLE ,9X,F4.2,/,
     *            5X,16HRISK MULTIPLIER ,7X,F5.2)
      WRITE(6,180) SURD,SURN
  180 FORMAT(2X,/,5X,20HSURVEILLANCE FACTORS,/,
     *  8X,9HDAYTIME  ,2X,F4.2,/,
     *  8X,9HNIGHTTIME,2X,F4.2,/)
C
      WRITE(6,190) PICD,PICN
  190 FORMAT(5X,16HPICKLING FACTORS,/,
     *  8X,9HDAYTIME  ,2X,F4.2,/,
     *  8X,9HNIGHTTIME,2X,F4.2,/)
      WRITE(6,200) PCTPOD,PCTPON
  200 FORMAT(5X,30HPERCENTAGE POPULATION OUTDOORS,/,
     *  8X,9HDAYTIME  ,2X,F4.2,/,
     *  8X,9HNIGHTTIME,2X,F4.2,/)
      WRITE(6,210) PDPLD,PDPLN,PDBD,PDBN
  210 FORMAT(5X,46HPROBABILITY DETECT AND AVOID DESCENDING OBJECT,/,
     *  8X,19HPAYLOAD (DAYTIME)  ,2X,F4.2,/,
     *  8X,19HPAYLOAD (NIGHTTIME),2X,F4.2,/,
     *  8X,19HBALLOON (DAYTIME)  ,2X,F4.2,/,
     *  8X,19HBALLOON (NIGHTTIME),2X,F4.2,/)
      WRITE(6,220) SPPL,SPBAL
  220 FORMAT(5X,28HSTRUCTUAL PROTECTION FACTORS,/,
     *  8X,14HHEAVY PAYLOADS,2X,F4.2,/,
     *  8X,14HHEAVY BALLOONS,2X,F4.2,/)
C
C     READ AND PRINT TOWN POPULATION DATA BASE
C
  230 NTOWN=NTOWN+1
      READ(2,235,END=240) NAMCNTY(NTOWN),NAMTOWN(NTOWN),TOWNLAT(NTOWN),
     * TOWNLON(NTOWN), TOWNPOP(NTOWN)
  235 FORMAT(A16,A20,3F11.2)
      IF(NAMCNTY(NTOWN).EQ.'ANDERSON        '.OR.NAMCNTY(NTOWN).EQ.'HEND
     *ERSON         '.OR.NAMCNTY(NTOWN).EQ.'CHEROKEE        '.OR.NAMCNTY(N
     *TOWN).EQ.'FREESTONE       '.OR.NAMCNTY(NTOWN).EQ.'HOUSTON
     *'.OR.NAMCNTY(NTOWN).EQ.'LEON            '.OR.NAMCNTY(NTOWN).EQ.'NA
     *VARRO          ') POPSUM=POPSUM+TOWNPOP(NTOWN)
      GO TO 230
  240 NTOWN=NTOWN-1
```

```
      WRITE(6,250)
  250 FORMAT(2X,/////,25X,25HTOWN POPULATION DATA BASE,///,3X,6HCOUNTY,
     * 13X,4HTOWN,15X,8HLATITUDE,2X,9HLONGITUDE,2X,10HPOPULATION,/)
      DO 270 I=1,NTOWN
      WRITE(6,260) NAMCNTY(I),NAMTOWN(I),TOWNLAT(I),TOWNLON(I),
     * TOWNPOP(I)
  260 FORMAT(1X,A16,A20,F10.2,1X,F10.2,3X,F8.0)
  270 CONTINUE
      WRITE(6,275) POPSUM
  275 FORMAT(2X,//,10X,24HTOTAL CITY POPULATION = ,F8.0)
C
C
C     CALCULATIONS
C
C     INCREMENT ALTITUDE
C
  300 ALT=ALT+DELALT
      IF(ALT.GT.HFLOAT) GO TO 400
C
C     RATIO DISPERSION
C
      PLD10=.10*DISPP
      PDISP=(ALT/70000.)*DISPP
      IF(PDISP.LT.PLD10) PDISP=PLD10
      IF(PDISP.GT.DISPP) PDISP=DISPP
      BALD10=.10*DISPB
      BDISP=(ALT/70000.)*DISPB
      IF(BDISP.LT.BALD10) BDISP=BALD10
      IF(BDISP.GT.DISPB) BDISP=DISPB
C
C     DETERMINE ASCENT VECTOR
C
      TBAL=0.0
      XBAL=0.0
      YBAL=0.0
      HASCNT=ALT
      IPRNT=IPRNT+1
      CALL ASCENT
C
C     DETERMINE DESCENT VECTOR
C
      TPLC=0.0
      XPLC=0.0
      YPLC=0.0
      HDSCNT=ALT
      VDSCNT=0.0
      CALL DESCNT
      BRPLC=BRATIO*RPLC
C
C     CALCULATE PAYLOAD IMPACT LATITUDE AND LONGITUDE
C
```

```
      XPLI=XBAL+XPLC
      YPLI=YBAL+YPLC
      RPLISQ=XPLI**2+YPLI**2
      RPLI=SQRT(RPLISQ)
      AXPLI=ABS(XPLI)
      IF(AXPLI.GT.0.0001) GO TO 310
      AZPLI=360.
      GO TO 320
  310 AZPLI=ATAN2(YPLI,XPLI)
      AZPLI=DEGPRAD*AZPLI
      IF(AZPLI.LE.0.0) GO TO 315
      AZPLI=90.-AZPLI
      IF(AZPLI.LT.0.0) AZPLI=AZPLI+360.
      GO TO 320
  315 AZPLI=ABS(AZPLI)+90.
  320 CONTINUE
      K=1
      N=3
      GD1=LAT/DEGPRAD
      L1=LONG/DEGPRAD
      R=RPLI
      AZ=AZPLI/DEGPRAD
      CALL OBLATE
      PLAT=GD2*DEGPRAD
      PLONG=L2*DEGPRAD
C
C     CALCULATE BALLOON IMPACT LATITUDE AND LONGITUDE
C
      XBI=XBAL+BRATIO*XPLC
      YBI=YBAL+BRATIO*YPLC
      RBISQ=XBI**2+YBI**2
      RBI=SQRT(RBISQ)
      AXBI=ABS(XBI)
      IF(AXBI.GT.0.0001) GO TO 330
      AZBI=360.
      GO TO 340
  330 AZBI=ATAN2(YBI,XBI)
      AZBI=DEGPRAD*AZBI
      IF(AZBI.LE.0.0) GO TO 335
      AZBI=90.0-AZBI
      IF(AZBI.LT.0.0) AZBI=AZBI+360.
      GO TO 340
  335 AZBI=ABS(AZBI)+90.
  340 CONTINUE
      R=RBI
      AZ=AZBI/DEGPRAD
      CALL OBLATE
      BLAT=GD2*DEGPRAD
      BLONG=L2*DEGPRAD
C
C     CALCULATE PROBABILITY OF IMPACTING AT THIS POINT
```

```
C
      DO 350 I=1,KLEVEL
      IF(ALT.GT.ELEVEL(I)) GO TO 350
      FALT=F*FA*FLEVEL(I)*DELALT/(ELEVEL(I)-BLEVEL(I))
      GO TO 360
  350 CONTINUE
      FALT=0.0
  360 CONTINUE
C
C     CALCULATE PAYLOAD AND BALLOON LETHAL AREAS
C
      CALL LETHAR
      PLAL=AMAX1(PLALB,PLALF)
C
C     CALCULATE PAYLOAD AND BALLOON RISK REDUCTION FACTORS
C
      PPROD=(1.-(PCTPOD*PDPLD+(1.-PCTPOD)*SPPL))
      PPRON=(1.-(PCTPON*PDPLN+(1.-PCTPON)*SPPL))
      BPROD=(1.-(PCTPOD*PDBD+(1.-PCTPOD)*SPBAL))
      BPRON=(1.-(PCTPON*PDBN+(1.-PCTPON)*SPBAL))
C
      XPD=(1.-SURD)*(1.-PICD)*PPROD
      XPN=(1.-SURN)*(1.-PICN)*PPRON
      XBD=(1.-SURD)*1.00*BPROD
      XBN=(1.-SURN)*1.00*BPRON
C
C     CALCULATE TOWN CASUALTY EXPECTATION
C
C     CALCULATE DISTANCES FROM PREDICTED PAYLOAD AND BALLOON
C       IMPACTS TO TOWN
C
      DO 370 I=1,NTOWN
      K=1
      N=1
      GD1=PLAT/DEGPRAD
      L1=PLONG/DEGPRAD
      GD2=TOWNLAT(I)/DEGPRAD
      L2=TOWNLON(I)/DEGPRAD
      CALL OBLATE
      DPLT=R/FTPNM
      SIGPL=DPLT/PDISP
C
      GD1=BLAT/DEGPRAD
      L1=BLONG/DEGPRAD
      CALL OBLATE
      DBT=R/FTPNM
      SIGB=DBT/BDISP
C
C     CALCULATE TOWN IMPACT PROBABILITY
C
```

```
      TWNSZ=SQRT(.001*TOWNPOP(I))
      SIG2=SIGPL+.10
      SIG1=SIGPL-.10
      EX2=-.5*SIG2**2
      EX1=-.5*SIG1**2
      IF(EX2.LT.-72.0) EX2=-72.0
      IF(EX1.LT.-72.0) EX1=-72.0
      P2=1.-EXP(EX2)
      P1=1.-EXP(EX1)
      R2=DPLT+.10*PDISP
      R1=DPLT-.10*PDISP
      TIPPL=(P2-P1)*TWNSZ/(PIE*(R2**2-R1**2))
C
      SIG2=SIGB+.10
      SIG1=SIGB-.10
      EX2=-.5*SIG2**2
      EX1=-.5*SIG1**2
      IF(EX2.LT.-72.0) EX2=-72.0
      IF(EX1.LT.-72.0) EX1=-72.0
      P2=1.-EXP(EX2)
      P1=1.-EXP(EX1)
      R2=DBT+.10*BDISP
      R1=DBT-.10*BDISP
      TIPBAL=(P2-P1)*TWNSZ/(PIE*(R2**2-R1**2))
C
C     CALCULATE TOWN CASUALTY EXPECTATION (DAY)
C
      C=5280.**2
      POPDEN=TOWNPOP(I)*POPADJ/TWNSZ
      CEPL=FALT*TIPPL*POPDEN*PLAL*(CNF*XPD+PCNF*XPD*AMULT+UCNF*1.0)/C
      CEBAL=FALT*TIPBAL*POPDEN*BALAL*(CNF*XBD+PCNF*XBD*AMULT+UCNF*
     *  BPROD)/C
      TOWNCED(I)=CEPL+CEBAL
      TWNCEDS(I)=TWNCEDS(I)+TOWNCED(I)
C
C     CALCULATE TOWN CASUALTY EXPECTATION (NIGHT)
C
      CEPL=FALT*TIPPL*POPDEN*PLAL*(CNF*XPN+PCNF*XPN*AMULT+UCNF*1.0)/C
      CEBAL=FALT*TIPBAL*POPDEN*BALAL*(CNF*XBN+PCNF*XBN*AMULT+UCNF*
     *  BPRON)/C
      TOWNCEN(I)=CEPL+CEBAL
      TWNCENS(I)=TWNCENS(I)+TOWNCEN(I)
  370 CONTINUE
      GO TO 300
C
C     CALCULATE RESIDUAL CASUALTY EXPECTATION
C
  400 CONTINUE
      PDENR=(TPOP-POPSUM)*POPADJ/TAREA
      CEPL=F*FA*PDENR*PLAL*(CNF*XPD+PCNF*XPD*AMULT+UCNF*1.0)/C
      CEBAL=F*FA*PDENR*BALAL*(CNF*XBD+PCNF*XBD*AMULT+UCNF*BPROD)/C
```

```
      CERESD=CEPL+CEBAL
C
      CEPL=F*FA*PDENR*PLAL*(CNF*XPN+PCNF*XPN*AMULT+UCNF*1.0)/C
      CEBAL=F*FA*PDENR*BALAL*(CNF*XBN+PCNF*XBN*AMULT+UCNF*BPRON)/C
      CERESN=CEPL+CEBAL
C
C     TOTAL CASUALTY EXPECTATION
C
      DO 410 I=1,NTOWN
      CETWND=CETWND+TWNCEDS(I)
  410 CETWNN=CETWNN+TWNCENS(I)
C
      CEDAY=CETWND+CERESD
      CENIGHT=CETWNN+CERESN
C
C     DETERMINE TOWN EXPOSED TO GREATEST RISK
C
      DO 420 I=1,NTOWN
      CETMAX2=AMAX1(CETMAX1,TWNCEDS(I),TWNCENS(I))
      IF(CETMAX2.LE.CETMAX1) GO TO 420
      CETMAX1=CETMAX2
      IMAX=I
  420 CONTINUE
      IAST(IMAX)=1H*
C
C
C     PRINT OUTPUTS
C
      WRITE(6,500) NAMSCI,NDATE,NAMSIT
  500 FORMAT(1H1,2X,///,40X,15H*** OUTPUTS ***,//,
     *  35X,25HBALLOON ASCENT RISK MODEL,///,
     *              1X,12HSCIENTIST:  ,A10,
     *                 12HLAUNCH DATE:,2X,A12,
     *                 12HLAUNCH SITE:,2X,A12,///,
     *   8X,6HCOUNTY,16X,4HTOWN,13X,8HCE (DAY),5X,10HCE (NIGHT),/)
      DO 520 I=1,NTOWN
      WRITE(6,510) NAMCNTY(I),NAMTOWN(I),TWNCEDS(I),TWNCENS(I),IAST(I)
  510 FORMAT(2X,A20,3X,A16,3X,E11.3,3X,E11.3,2X,A1)
  520 CONTINUE
      WRITE(6,530) CETWND,CETWNN
  530 FORMAT(2X,//,6X,13HTOTAL TOWN CE,25X,E11.3,3X,E11.3)
      WRITE(6,540) CERESD,CERESN
  540 FORMAT(2X,/,6X,11HRESIDUAL CE,27X,E11.3,3X,E11.3,/,
     * 47X,8H--------,6X,8H--------)
      WRITE(6,550) CEDAY,CENIGHT
  550 FORMAT(2X,/,6X,8HTOTAL CE,30X,E11.3,3X,E11.3)
      WRITE(6,560)
  560 FORMAT(2X,//,6X,19H* MAXIMUM RISK TOWN)
C
      STOP
      END
```

```
      SUBROUTINE ASCENT
C
C     CALCULATES BALLOON ASCENT VECTOR
C
C     WRITTEN BY:
C       ROB BEYMA
C       NOVEMBER 1987
C
C
      COMMON /BA/ HASCNT,VASCNT,TBAL,XBAL,YBAL,RBAL,AZBAL,TDEL
      COMMON /WW/ NLEVEL,ILEVEL,RDIRA(15),SPEEDA(15),IPRNT
C
C
      H1=0.0
      NCNT=1
C
      IF(IPRNT.LE.2) WRITE(6,10)
   10 FORMAT(1H1,5X,4HTBAL,6X,2HH1,6X,4HXBAL,6X,4HYBAL,5X,4HRBAL,
     * 3X,5HAZBAL,/)
C
C     CALCULATE ASCENT PARAMETERS
C
   20 INDX=H1/ILEVEL + 1
      IF(INDX.GT.NLEVEL) INDX=NLEVEL
C
      RDIR=270.-RDIRA(INDX)
      IF(RDIR.LT.0.0) RDIR=RDIR+360.
      RDIR=RDIR/57.29577951
      SPEED=SPEEDA(INDX)
C
      XBAL=XBAL + SPEED*COS(RDIR)*TDEL
      YBAL=YBAL + SPEED*SIN(RDIR)*TDEL
      RSQ=XBAL**2+YBAL**2
      RBAL=SQRT(RSQ)
C
      AXBAL=ABS(XBAL)
      IF(AXBAL.GT.0.0001) GO TO 30
      AZBAL=360.
      GO TO 40
   30 AZBAL=ATAN2(YBAL,XBAL)
      AZBAL=57.29577951*AZBAL
      IF(AZBAL.LE.0.0) GO TO 35
      AZBAL=90.-AZBAL
      IF(AZBAL.LT.0.0) AZBAL=AZBAL+360.
      GO TO 40
   35 AZBAL=ABS(AZBAL)+90.
C
   40 H1=H1 + VASCNT*TDEL
      TBAL=TBAL + TDEL
C
C     PRINT ASCENT PARAMETERS
```

```
C
C
      IF(NCNT.LT.60) GO TO 60
      IF(IPRNT.GT.2) GO TO 60
      WRITE(6,50) TBAL,H1,XBAL,YBAL,RBAL,AZBAL
   50 FORMAT(5X,F5.0,2X,F7.0,2X,F8.0,2X,F8.0,2X,F7.0,2X,F5.1)
      NCNT=0
   60 NCNT=NCNT+1
C
      IF(H1.LT.HASCNT) GO TO 20
C
C     CALCULATE AND PRINT SUMMARY
C
      TMIN=TBAL/60.
      RNM=RBAL/6076.1155
C
      WRITE(6,70) TMIN,RNM,AZBAL
   70 FORMAT(2X,///,5X,16HASCENT TIME    = ,F5.1,9H  MINUTES,/,5X,
     * 16HDRIFT RANGE   = ,F6.2,4H  NM,/,5X,16HDRIFT AZIMUTH = ,
     * F5.1,5H  DEG)
C
      RETURN
      END
      SUBROUTINE DESCNT
C
C     CALCULATES PAYLOAD/CHUTE DESCENT VECTOR
C
C     WRITTEN BY:
C       ROB BEYMA
C       NOVEMBER 1987
C
C
      COMMON /PD/ HDSCNT,VDSCNT,TPLC,XPLC,YPLC,RPLC,AZPLC,DELT,
     * WPLC,CD,S
      COMMON /WW/ NLEVEL,ILEVEL,RDIRA(15),SPEEDA(15),IPRNT
C
C
      H1=HDSCNT
      V1=VDSCNT
      AMASS=WPLC/32.174
      NCNT=1
C
      PZ=29.92
      TZ=518.6
      RHOZ=.002378
C
      IF(IPRNT.LE.2) WRITE(6,10)
   10 FORMAT(1H1,5X,4HTPLC,6X,2HH2,6X,2HV2,6X,4HXPLC,6X,4HYPLC,
     * 5X,4HRPLC,3X,5HAZPLC,/)
C
C     CALCULATE DESCENT PARAMETERS
```

```
C
   20 CONTINUE
C
C     CALCULATE DENSITY
C
      IF(H1.GT.36500.) GO TO 25
      P=(1.91-.01315*H1/1000.)**5.256
      T=59.0 + 459.6 - 1.0*H1/280.
      GO TO 27
   25 EX=1.69-.0478*H1/1000.
      P=6.94*EXP(EX)
      T=-69.7 + 459.6
   27 RHO=RHOZ*(P/PZ)*(TZ/T)
C
C     CALCULATE VERTICAL DESCENT PARAMETERS
C
      D=.5*RHO*V1**2*CD*S
      F=WPLC - D
      A=F/AMASS
      V2=V1 + A*DELT
      H2=H1 - 0.5*(V1+V2)*DELT
      TPLC=TPLC + DELT
C
C     CALCULATE HORIZONTAL DESCENT PARAMETERS
C
      INDX=H1/ILEVEL + 1
      IF(INDX.GT.NLEVEL) INDX=NLEVEL
C
      RDIR=270. - RDIRA(INDX)
      IF(RDIR.LT.0.0) RDIR=RDIR + 360.
      RDIR=RDIR/57.29577951
      SPEED=SPEEDA(INDX)
C
      XPLC=XPLC + SPEED*COS(RDIR)*DELT
      YPLC=YPLC + SPEED*SIN(RDIR)*DELT
      RSQ=XPLC**2 + YPLC**2
      RPLC=SQRT(RSQ)
C
      AXPLC=ABS(XPLC)
      IF(AXPLC.GT.0.0001) GO TO 30
      AZPLC=360.
      GO TO 40
   30 AZPLC=ATAN2(YPLC,XPLC)
      AZPLC=57.29577951*AZPLC
      IF(AZPLC.LE.0.0) GO TO 35
      AZPLC=90. - AZPLC
      IF(AZPLC.LT.0.0) AZPLC=AZPLC + 360.
      GO TO 40
   35 AZPLC=ABS(AZPLC) + 90.
C
C     PRINT DESCENT PARAMETERS
```

```
C
   40 CONTINUE
      IF(NCNT.LT.600) GO TO 50
      IF(IPRNT.GT.2) GO TO 50
      WRITE(6,45) TPLC,H2,V2,XPLC,YPLC,RPLC,AZPLC
   45 FORMAT(5X,F5.0,2X,F7.0,2X,F6.1,2X,F8.0,2X,F8.0,2X,F7.0,2X,F5.1)
      NCNT=0
   50 NCNT=NCNT+1
C
      V1=V2
      H1=H2
C
      IF(H2.GT.0.0) GO TO 20
C
C     CALCULATE AND PRINT SUMMARY
C
      TMIN=TPLC/60.
      RNM=RPLC/6076.1155
C
      WRITE(6,60) TMIN,RNM,AZPLC
   60 FORMAT(2X,////,5X,16HDESCENT TIME  = ,F5.1,9H  MINUTES,/,5X,
     * 16HDRIFT RANGE   = ,F6.2,4H  NM,/,5X,16HDRIFT AZIMUTH = ,
     * F5.1,5H  DEG)
C
      RETURN
      END
               SUBROUTINE LETHAR
C
C    WRITTEN :
C         BY - JAMES E. GLADDING
C         DATE - 1/29/86
C
C
C         PLLEN = PAYLOAD LENGTH(FT.)
C         PLWID = PAYLOAD WIDTH(FT.)
C         PLRAD = PAYLOAD RADUS IF ROUND BASE(FT.)
C         PLHGT = PAYLOAD HEIGHT(FT.)
C         BALVOL = BALLOON VOLUME(MILLIONS OF CUBIC FEET)
C         BALWT = BALLOON WEIGHT(LBS.)
C         PLALB = PAYLOAD BASE LETHAL AREA(SQ.FT.)
C         PLALF = PAYLOAD FACE LETHAL AREA(SQ.FT.)
C         BALAL = BALLOON LETHAL AREA(SQ.FT.)
C
C
      COMMON/B/PLLEN,PLWID,PLHGT,PLRAD,BALVOL,BALWT,PLALB,PLALF,BALAL
      REAL L
C
C            ADD 1 FOOT BUFFER TO DIMENSIONS
C
      L = PLLEN + 2
      W = PLWID + 2
```

```
      H = PLHGT + 2
C
C             CALCULATE BASE AREA OF PAYLOAD
C
      IF(PLRAD .EQ. 0.0)PLALB = L*W
      IF(PLRAD .NE. 0.0)PLALB = 3.1415927*((PLRAD+1)**2)
C
C             CALCULATE FACE AREA OF PAYLOAD
C
      IF(W.GT.L) L=W
      IF(PLRAD.EQ.0.0) PLALF=L*H
      IF(PLRAD.NE.0.0) PLALF=2*(PLRAD+1.)*H
C
      IF(H/PLALB .GT. .5) PLALB = PLALF
C
C             CALCULATE LETHAL AREA OF BALOON
C
      BAL1 = 2.5*(SQRT(BALWT))
      BAL2 = 55.0*(BALVOL**(1./3.))
      BALAL = (BAL1+BAL2)/2.0
C
      RETURN
      END
      SUBROUTINE OBLATE
C
C
C     SUBROUTINE OBLATE, W. E. MELSON, RANGE SAFETY, WALLOPS ISLAND, VA.
C
C     PURPOSE        COMPUTES SURFACE PARAMETERS OF THE EARTH
C
C     INPUTS            N      = OPTION CONTROL ONE THRU EIGHT
C                 IF N IS EQUAL TO
C                   *1* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                       L1   = INITIAL LONGITUDE IN RADIANS
C                       GD2  = FINAL GEODETIC LATITUDE IN RADIANS
C                       L2   = FINAL LONGITUDE IN RADIANS
C                       K    = QUADRANT CONTROL ONE THRU THREE
C                     IF K IS EQUAL TO
C                       (1)     AZIMUTH 0 THRU 360 DEG AND RANGE ANGLE 0
C                               THRU 180 DEG
C                       (2)     AZIMUTH 0 THRU 180 DEG AND RANGE ANGLE 0
C                               THRU 360 DEG
C                       (3)     AZIMUTH 180 THRU 360 DEG AND RANGE ANGLE 0
C                               THRU 360 DEG
C                   *2* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                       L1   = INITIAL LONGITUDE IN RADIANS
C                       GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                       L2   = FINAL LONGITUDE IN RADIANS
C                       K    = QUADRANT CONTROL ONE THRU THREE
C                     IF K IS EQUAL TO
C                       (1)     AZIMUTH 0 THRU 360 DEG AND RANGE ANGLE 0
```

```
C                           THRU 180 DEG
C                    (2)    AZIMUTH 0 THRU 180 DEG AND RANGE ANGLE 0
C                           THRU 360 DEG
C                    (3)    AZIMUTH 180 THRU 360 DEG AND RANGE ANGLE 0
C                           THRU 360 DEG
C                *3* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                    L1   = INITIAL LONGITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    R    = RANGE OVER THE EARTH SURFACE IN FEET
C                *4* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                    L1   = INITIAL LONGITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    R    = RANGE OVER EARTH SURFACE IN FEET
C                *5* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                    L1   = INITIAL LONGITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    AG   = RANGE ANGLE IN RADIANS
C                *6* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                    L1   = INITIAL LONGITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    AG   = RANGE ANGLE IN RADIANS
C                *7* GD1  = GEODETIC LATITUDE IN RADIANS
C                *8* GC1  = GEOCENTRIC LATITUDE IN RADIANS
C
C     OUTPUTS          RL     = AVERAGE LOCAL RADIUS OF THE EARTH IN FEET
C                      V      = MAX AND MIN RADIUS VARIANCE IN FEET
C             IF N IS EQUAL TO
C                *1* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                    GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    R    = RANGE OVER EARTH SURFACE IN FEET
C                    AG   = RANGE ANGLE IN RADIANS
C                *2* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                    GD2  = FINAL GEODETIC LATITUDE IN RADIANS
C                    AZ   = AZIMUTH FROM TRUE NORTH IN RADIANS
C                    R    = RANGE OVER EARTH SURFACE IN FEET
C                    AG   = RANGE ANGLE IN FEET
C                *3* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                    GD2  = FINAL GEODETIC LATITUDE IN RADIANS
C                    GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                    L2   = FINAL LONGITUDE IN RADIANS
C                    AG   = RANGE ANGLE IN RADIANS
C                    K    = ZERO
C                *4* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                    GD2  = FINAL GEODETIC LATITUDE IN RADIANS
C                    GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                    L2   = FINAL LONGITUDE IN RADIANS
C                    AG   = RANGE ANGLE IN RADIANS
C                    K    = ZERO
C                *5* GC1  = INITIAL GEOCENTRIC LATITUDE IN RADIANS
C                    GD2  = FINAL GEODETIC LATITUDE IN RADIANS
```

```
C                      GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                      L2   = FINAL LONGITUDE IN RADIANS
C                      R    = RANGE OVER EARTH SURFACE IN FEET
C                      K    = ZERO
C                  *6* GD1  = INITIAL GEODETIC LATITUDE IN RADIANS
C                      GD2  = FINAL GEODETIC LATITUDE IN RADIANS
C                      GC2  = FINAL GEOCENTRIC LATITUDE IN RADIANS
C                      L2   = FINAL LONGITUDE IN RADIANS
C                      R    = RANGE OVER EARTH SURFACE IN FEET
C                      K    = ZERO
C                  *7* GC1  = GEOCENTRIC LATITUDE IN RADIANS
C                  *8* GD1  = GEODETIC LATITUDE IN RADIANS
C
C     SUBPROGRAMS   *
C
C     COMMENTS      PI,PITWO AND TWO PI ARE REQUIRED BY THIS ROUTINE.
C                   THEY ARE COMPUTED EXTERNAL TO THIS ROUTINE AND SENT
C                   IN COMMON.
C
C     ASSUMPTIONS   1. EARTH IS AN OBLATE SPHERIOD, AN ELLIPSOID OF
C                      REVOLUTION, WITH POLAR RADIUS EQUAL TO SEMIMINOR
C                      AXIS AND EQUATORIAL RADIUS EQUAL TO SEMIMAJOR AXI
C                   2. THE SECTION OVER THE SURFACE OF THE EARTH WHICH
C                      IS BEING CONSIDERED WILL BE BASED ON A SPHERE
C                      WITH A CALCULATED AVERAGE LOCAL RADIUS,DISTANCE
C                      FROM THE GEOMETRIC CENTER TO THE SURFACE OF THE
C                      EARTH IN QUESTION,FOR DETERMINING GEOCENTRIC
C                      PARAMETERS.
C                   3. THE EARTH IS A FISHER MODEL WITH THE POLAR RADIUS
C                      EQUAL TO 20855591 FEET AND THE EQUATORIAL RADIUS
C                      EQUAL TO 20925741 FEET.
C
C     REMARKS       1. LONGITUDES WEST OF THE MERIDIAN OF GREENWICH ARE
C                      NEGATIVE
C                   2. LONGITUDES EAST OF THE MERIDIAN OF GREENWICH ARE
C                      POSITIVE
C                   3. LATITUDES IN THE NORTHERN HEMISPHERE ARE POSITIVE
C                   4. LATITUDES IN THE SOUTHERN HEMISPHERE ARE NEGATIVE
C                   5. THE AVERAGE LOCAL RADIUS IS DETERMINED FROM THE
C                      AVERAGE OF THREE POINTS, THE INITIAL, FINAL, AND
C                      MIDPOINT RADIUS.
C                   6. THE ACCURACY RELATED TO THE METHOD OF CALCULATION
C                      OF THE AVERAGE LOCAL RADIUS CAN NOT BE INSURED
C                      FOR RANGES WHICH ACCUMULATE OVER A TOTAL OF 45
C                      DEGREES IN LATITUDE.
C
C         * OUTPUT FILES
C           LO - ERROR MESSAGES
C
C         * SYSTEM DEPENDENT FEATURES
C           DATAPOOL
```

```
C
C         * MODIFICATION HISTORY
C           PROGRAMMER          DATE         MODIFICATION
C
C          EDWARD JUSTICE      11/10/82    MODIFIED SUBROUTINE OBLATE
C                                           TO BE USED ON FORTY COMPILER
C                                           USED BLOCK DATA CONSTANTS
C          ANNETTE CONGER      08/08/83    CLEANUP UNNECESSARY CODE
C                                           (COMPUTED GO TO'S) AND
C                                           USE FUNCTIONS TO PERFORM
C                                           TRIGONOMETRIC CALCULATIONS
C                                           FOR EASIER PROGRAM
C                                           READABILITY AND MAIN-
C                                           TENANCE.
C          ANNETTE CONGER      02/15/85    CONVERSION TO GOULD
C
C//
      COMMON/AAA/RP,AE,GC1,GC2,AZ,R,AG,EC,RL,N,K,V ,M
      COMMON/BB/GD1,L1,GD2,L2
      COMMON/DATAPOOL/PI,PITWO,TWOPI
      DOUBLE PRECISION GEOCEN,GEODET,LONGDEL,RADLAUNC,GCANGCOM,GCANG
      DOUBLE PRECISION RP,AE,GD1,GC1,L1,GD2,GC2,L2,AZ,R,AG,VALUE
      DOUBLE PRECISION ECSQ,GD,GC,RL1,RLH,AG1,DL,GCS,V,RL2,RL3,RLL,RL
     1,COSAG,SGC2,EC,AAZ
      DOUBLE PRECISION PI,PITWO,TWOPI
C
C        FUNCTIONS FOR TRIGINOMETRIC CALCULATIONS
C
C        COMPUTE GEOCENTRIC LATITUDE
C
      GEOCEN(GC) = DATAN2((RP/AE)**2*DSIN(GC),DCOS(GC))
C
C        COMPUTE GEODETIC LATITUDE
C
      GEODET(GD) = DATAN2((AE/RP)**2*DSIN(GD),DCOS(GD))
C
C        COMPUTE LONGITUDE DELTA FROM INITIAL LATITUDE
C
      LONGDEL(AG,AZ,GC1)=DATAN2(DSIN(AG)*DSIN(AZ),DCOS(AG)*DCOS(GC1)
     1   -DSIN(GC1)*DSIN(AG)*DCOS(AZ))
C
C        COMPUTE RADIUS AT LAUNCHER
C
      RADLAUNC(GC)=RP/DSQRT(1.-ECSQ*DCOS(GC)**2)
C
C        COMPONENT FOR COMPUTING GEOCENTRIC ANGLE
C
      GCANGCOM(AG,GC1,AZ) = DCOS(AG)*DSIN(GC1) + DSIN(AG)*DCOS(GC1)
     & *DCOS(AZ)
C
C        COMPUTE GEOCENTRIC ANGLE
```

```
C
      GCANG(SGC2) = DATAN2(SGC2,DSQRT(1.0 - SGC2**2))
C
C**** FORMATS*****
C
  400 FORMAT(1H0,59('X*'),'X')
  401 FORMAT(12X,'INPUT ERROR TO SUBROUTINE OBLATE, CONTROL , FATAL ',
     1 10X,I5,5X,I5)
  402 FORMAT(12X,'INPUT ERROR TO SUBROUTINE OBLATE, DATA , NON-FATAL ',
     110X,I3,10X,'VALUE = ',F16.9)
 403  FORMAT (1X,59('X*'),'X'//)
C
C     INITIALIZATION
C
      RP=20855591.0D0
      AE=20925741.0D0
C
C     INPUT CHECKS
C
      IF(N.LE.0.OR.N.GT.8) GO TO 6000
      IF((N.EQ.1.OR.N.EQ.2).AND.(K.LE.0.OR.K.GT.3)) GO TO 6000
      IF(N.EQ.1.OR.N.EQ.3.OR.N.EQ.5.OR.N.EQ.7) GO TO 22
      GO TO 23
   22 IF((DABS(GD1) - PITWO) .GT. 1.0D-7) GO TO 6002
      GO TO 24
   23 IF((DABS(GC1) - PITWO) .GT. 1.0D-7) GO TO 6003
   24 IF(N.EQ.1.OR.N.EQ.2) GO TO 25
      GO TO 27
   25 IF((DABS(L2)-PI).GT.1.0D-7) GO TO 6004
      IF(N.NE.1) GO TO 26
IF((DABS(GD2) - PITWO) .GT. 1.0D-7) GO TO 6005
      GO TO 32
   26 IF((DABS(GC2) - PITWO) .GT. 1.0D-7) GO TO 6006
      GO TO 32
   27 IF(N.EQ.3.OR.N.EQ.4.OR.N.EQ.5.OR.N.EQ.6) GO TO 28
      GO TO 31
   28 IF(AZ.GT.TWOPI.OR.AZ.LT.0.0) GO TO 6007
      IF(N.EQ.3.OR.N.EQ.4) GO TO 29
      GO TO 30
   29 IF(R.GT.TWOPI*AE.OR.R.LT.0.0) GO TO 6008
      GO TO 32
   30 IF(AG.GT.TWOPI.OR.AG.LT.0.0) GO TO 6009
   31 IF(N.EQ.7.OR.N.EQ.8) GO TO 33
      GO TO 32
   32 IF((DABS(L1) - PI) .GT. 1.0D-7) GO TO 6010
   33 ECSQ=1.-(RP/AE)**2
C
C     LOGIC ROUTINE
C
      IF(N.EQ.1) GO TO 1000
      IF(N.EQ.2) GO TO 2000
```

```
      IF(N.EQ.3.OR.N.EQ.5) GO TO 3000
      IF(N.EQ.4.OR.N.EQ.6) GO TO 4000
      IF(N.EQ.7) GO TO 5000
      IF(N.EQ.8) GO TO 5500
C
 1000 GC1=GEOCEN(GD1)
      GC2=GEOCEN(GD2)
      GO TO 100
C
 2000 GD1=GEODET(GC1)
      GD2=GEODET(GC2)
  100 RL1=RADLAUNC(GC1)
      RL2=RADLAUNC(GC2)
      RL=(RL1+RL2)/2.
      RLH=RL
      AZ=DATAN2(DCOS(GC2)*DSIN(L2-L1),DCOS(GC1)*DSIN(GC2)-DSIN(GC1)
     1   *DCOS(GC2)*DCOS(L2-L1))
      AAZ=AZ
      IF(K.EQ.1) GO TO 721
      IF(K.EQ.2) GO TO 722
      IF(K.EQ.3) GO TO 723
  721 IF(AZ.LT.0.0) AZ=TWOPI+AZ
      GO TO 7003
  722 IF(AZ.LT.0.0) AZ=PI+AZ
      GO TO 7003
  723 IF(AZ.GT.0.0.AND.AZ.LT.PI) AZ=PI+AZ
      IF(AZ.LT.0.0) AZ=TWOPI+AZ
 7003 COSAG = DSIN(GC1)*DSIN(GC2) + DCOS(GC1)*DCOS(GC2)*DCOS(L2-L1)
      AG = DATAN2(DSQRT(1.0 - COSAG**2),COSAG)
      IF(K.EQ.1) GO TO 731
      IF(K.EQ.2) GO TO 732
      IF(K.EQ.3) GO TO 733
  731 IF(AG.LT.0.0) AG=DABS(AG)
      GO TO 1053
  732 IF(AAZ.LT.0.0) AG = TWOPI - AG
      GO TO 1053
  733 IF((AAZ.LT.PI).AND.(AAZ.GT.0.0)) AG = TWOPI - AG
 1053 AG1=AG
      AG=AG/2.
      DL=LONGDEL(AG,AZ,GC1)
      SGC2 = GCANGCOM(AG,GC1,AZ)
      GCS = GCANG(SGC2)
      RL3=RADLAUNC(GCS)
      RL = (RL1 + 2.*RL3 + RL2)/4.
      AG=AG1
      R = AG*RL
      GO TO 7010
C
 3000 GC1=GEOCEN(GD1)
      GO TO 300
```

```
C
 4000 GD1=GEODET(GC1)
  300 RL1=RADLAUNC(GC1)
      IF(N.NE.5.AND.N.NE.6) AG = R/RL1
      DL=LONGDEL(AG,AZ,GC1)
      SGC2 = GCANGCOM(AG,GC1,AZ)
      GCS = GCANG(SGC2)
      RL2=RADLAUNC(GCS)
      RL=(RL1+RL2)/2.
      RLH=RL
      IF(N.NE.5.AND.N.NE.6) AG = R/RL
      AG1=AG
      AG=AG/2.
      DL=LONGDEL(AG,AZ,GC1)
      SGC2 = GCANGCOM(AG,GC1,AZ)
      GCS = GCANG(SGC2)
      RL3=RADLAUNC(GCS)
      RL = (RL1 + 2.*RL3 + RL2)/4.
      AG=AG1
      IF(N.NE.5.AND.N.NE.6) AG = R/RL
      DL=LONGDEL(AG,AZ,GC1)
      L2=DL+L1
      IF(L2.LT.(-PI)) L2=TWOPI+L2
      IF(L2.GT.PI) L2=L2-TWOPI
      SGC2 = GCANGCOM(AG,GC1,AZ)
      GCS = GCANG(SGC2)
      GC2=GCS
      IF(N.NE.3.AND.N.NE.4) R = AG*RL
      GD2=GEODET(GC2)
      K=0
      GO TO 7010
C
 5000 GC1=GEOCEN(GD1)
      GO TO 500
C
 5500 GD1=GEODET(GC1)
  500 RL=RADLAUNC(GC1)
      GC2=GC1
      GD2=GD1
      AZ=0.0D0
      R=0.0D0
      V=0.0D0
      AG=0.0D0
      K=0
      L1=0.0D0
      L2=0.0D0
      GO TO 8000
 7010 IF(RL1.GT.RL2) GO TO 743
      IF(RL2.GT.RL3) GO TO 741
      RLH=RL3
      RLL=RL1
```

```
      GO TO 746
  741 RLH=RL2
      IF(RL1.GT.RL3) GO TO 742
      RLL=RL1
      GO TO 746
  742 RLL=RL3
      GO TO 746
  743 IF(RL1.GT.RL3) GO TO 744
      RLH=RL3
      RLL=RL2
      GO TO 746
  744 RLH=RL1
      IF(RL2.GT.RL3) GO TO 745
      RLL=RL2
      GO TO 746
  745 RLL=RL3
  746 V=RLH-RLL
      GO TO 8000
C
C     INPUT ERROR
C
 6002 IX = 22
      VALUE = GD1
      GO TO 6001
 6003 IX = 23
      VALUE = GC1
      GO TO 6001
 6004 IX = 251
      VALUE = L2
      GO TO 6001
 6005 IX = 252
      VALUE = GD2
      GO TO 6001
 6006 IX = 26
      VALUE = GC2
      GO TO 6001
 6007 IX = 28
      VALUE = AZ
      GO TO 6001
 6008 IX = 29
      VALUE = R
      GO TO 6001
 6009 IX = 30
      VALUE = AG
      GO TO 6001
 6010 IX = 32
      VALUE = L1
 6001 PRINT 400
      PRINT 402 ,IX,VALUE
      PRINT 403
      GO TO 33
```

```
 6000 PRINT 400
      PRINT 401, N,K
      PRINT 403
 8000 RETURN
C
        END
```

APPENDIX 3

TOWN POPULATION DATA BASE

COUNTY	TOWN	LATITUDE	LONGITUDE	POPULATION
ANDERSON	ELKHART	31.63	-95.59	1317.
ANDERSON	FRANKSTON	32.04	-95.34	1255.
ANDERSON	PALESTINE	31.76	-95.69	15948.
ANGELINA	BURKE	32.21	-94.80	322.
ANGELINA	DIBOLL	32.16	-94.81	5227.
ANGELINA	HUDSON	31.31	-94.80	1659.
ANGELINA	LUFKIN	32.32	-94.76	28562.
CHEROKEE	ALTO	31.63	-95.09	1203.
CHEROKEE	GALLLATIN	31.89	-95.18	132.
CHEROKEE	JACKSONVILLE	31.92	-95.28	12264.
CHEROKEE	NEW SUMMERFIELD	31.96	-95.10	319.
CHEROKEE	REKLAW	31.86	-95.00	305.
CHEROKEE	RUSK	31.79	-95.16	4681.
CHEROKEE	WELLS	31.50	-94.96	926.
FREESTONE	FAIRFIELD	31.71	-96.18	3505.
FREESTONE	KIRVIN	31.76	-96.34	107.
FREESTONE	OAKWOOD	31.56	-95.88	606.
FREESTONE	STREETMAN	31.87	-96.45	415.
FREESTONE	TEAGUE	31.62	-96.30	3390.
FREESTONE	WORTHAM	31.78	-96.49	1187.
GREGG	CLARKSVILLE CITY	32.50	-94.92	525.
GREGG	GLADEWATER	32.51	-94.98	6548.
GREGG	KILGORE	32.39	-94.89	10968.
GREGG	LIBERTY CITY	32.42	-94.96	1121.
GREGG	ROLLING MEADOWS	32.41	-94.83	252.
GREGG	WARREN CITY	32.51	-94.96	281.
HENDERSON	ATHENS	32.19	-95.86	10197.
HENDERSON	BERRYVILLE	32.08	-95.50	513.
HENDERSON	BROWNSBORO	32.30	-95.62	582.
HENDERSON	CANEY CITY	32.21	-96.04	312.
HENDERSON	CHANDLER	32.31	-95.50	1308.
HENDERSON	COFFEE CITY	32.10	-95.53	254.
HENDERSON	ENCHANTED OAKS	32.26	-96.12	212.
HENDERSON	EUSTACE	32.30	-96.02	541.
HENDERSON	GUN BARRELL CITY	32.32	-96.15	2118.
HENDERSON	MABANK	32.36	-96.11	1443.
HENDERSON	MALAKOFF CITY	32.17	-96.02	2082.
HENDERSON	MOORE STATION	32.18	-95.58	335.
HENDERSON	MURCHISON	32.27	-95.77	513.
HENDERSON	PAYNE SPRINGS	32.28	-96.09	422.
HENDERSON	POYNOR	32.06	-95.60	272.
HENDERSON	SEVEN POINTS	32.31	-96.20	647.
HENDERSON	STAR HARBOR	32.19	-96.06	310.
HENDERSON	TOOL	32.27	-96.17	1591.
HENDERSON	TRINIDAD	32.14	-96.12	1130.
HOUSTON	CROCKETT	31.30	-95.48	7405.

HOUSTON	GRAPELAND	31.50	-95.51	1634.
HOUSTON	KENNARD	31.35	-95.20	424.
HOUSTON	LATEXO	31.40	-95.50	312.
HOUSTON	LOVELADY	31.10	-95.46	509.
KAUFMAN	KAUFMAN	32.57	-96.32	4658.
KAUFMAN	KEMP	32.42	-96.24	1035.
KAUFMAN	OAK GROVE	32.51	-96.34	319.
KAUFMAN	OAK RIDGE	32.64	-96.28	247.
KAUFMAN	POST OAK BEND CITY	32.62	-96.34	878.
KAUFMAN	TERRELL	32.62	-96.32	13225.
LEON	BUFFALO	31.44	-96.80	1507.
LEON	CENTERVILLE	31.24	-96.00	799.
LEON	JEWETT	31.35	-96.16	597.
LEON	LEONA	31.13	-96.00	165.
LEON	MARQUEZ	31.21	-96.28	231.
LEON	NORMANGEE	31.02	-96.13	636.
LIMESTONE	COOLIDGE	31.74	-96.66	810.
LIMESTONE	GROESBECK	31.50	-96.58	3373.
LIMESTONE	KOSSE	31.30	-96.66	484.
LIMESTONE	MEXIA	31.78	-96.50	7094.
LIMESTONE	TEHUACANA	31.72	-96.56	265.
LIMESTONE	THORNTON	31.40	-96.58	498.
MADISON	MADISONVILLE	30.94	-95.92	5385.
NACOGDOCHES	APPLEBY	31.71	-94.61	453.
NACOGDOCHES	CUSHING	31.80	-94.86	518.
NAVARRO	ANGUS	31.98	-96.45	244.
NAVARRO	BARRY	32.09	-96.65	192.
NAVARRO	BLOOMING GROVE	32.07	-96.72	823.
NAVARRO	CORSICANA	32.08	-96.50	21712.
NAVARRO	DAWSON	31.89	-96.74	747.
NAVARRO	EMHOUSE	32.13	-96.59	197.
NAVARRO	FROST	32.08	-96.81	564.
NAVARRO	GOODLOW	32.08	-96.23	343.
NAVARRO	KERENS	32.11	-96.24	1582.
NAVARRO	MUSTANG	32.01	-96.46	12.
NAVARRO	POWELL	32.10	-96.34	111.
NAVARRO	RETREAT	32.04	-96.51	255.
NAVARRO	RICE	32.22	-96.52	439.
NAVARRO	RICHLAND	31.92	-96.46	260.
RUSK	HENDERSON	32.13	-94.82	11473.
RUSK	MOUNT ENTERPRISE	31.90	-94.86	485.
RUSK	OVERTON	32.28	-95.00	2430.
SMITH	ARP	32.22	-95.06	939.
SMITH	BULLARD	32.12	-95.34	681.
SMITH	LINDALE	32.52	-95.42	2180.
SMITH	NEW CHAPEL HILL	32.30	-95.20	618.
SMITH	TROUP	32.14	-95.16	1911.
SMITH	TYLER	32.34	-95.32	70508.
SMITH	WIITEHOUSE	32.22	-95.24	2172.
SMITH	WINONA	32.50	-95.18	443.
TRINITY	GROVETON	30.94	-95.14	1262.

TRINITY	TRINITY	31.04	-95.38	2620.
UPSHUR	BIG SANDY	32.58	-95.12	1258.
VAN ZANDT	CANTON	32.56	-95.89	2845.
VAN ZANDT	EDGEWOOD	32.68	-95.90	1413.
VAN ZANDT	EDOM	32.38	-95.60	250.
VAN ZANDT	FRUITVALE	32.66	-95.82	367.
VAN ZANDT	GRAND SALINE	32.66	-95.74	2709.
VAN ZANDT	VAN	32.50	-95.64	1881.
VAN ZANDT	WILLS POINT	32.69	-96.00	2631.
WOOD	HAWKINS	32.58	-95.21	1302.
WOOD	MINEOLA	32.65	-95.50	4346.

TOTAL CITY POPULATION = 114042.

APPENDIX 4

*** INPUTS ***

SCIENTIST BEYMA
LAUNCH DATE JULY 1988
LAUNCH SITE PALESTINE
TIME OF DAY DAY

LATITUDE 31.783
LONGITUDE -95.717

BALLOON VOLUME (MILLIONS CUBIC FT)	27.00
BALLOON WEIGHT (LBS)	3000.
PAYLOAD LENGTH (FT)	6.00
PAYLOAD WIDTH (FT)	6.00
PAYLOAD HEIGHT (FT)	4.00
PAYLOAD RADIUS (FT)	.00

FLOAT ALTITUDE (FT) 110000.
CLIMB RATE (FT/SEC) 15.00

PAYLOAD/CHUTE WEIGHT (LBS)	3000.
CHUTE DRAG COEFFICIENT	.75
CHUTE REFERENCE AREA (FT2)	7854.00
1-SIGMA PAYLOAD DISPERSION (NM)	5.54
1-SIGMA BALLOON DISPERSION (NM)	5.57

MEAN BALLOON/PAYLOAD IMPACT RANGE RATIO .43

NUMBER OF WIND LEVELS 11
DEPTH OF WIND LEVELS (FT) 10000

0 - 10000 FT	270.0 DEG	10.0 FT/SEC
10000 - 20000 FT	270.0 DEG	20.0 FT/SEC
20000 - 30000 FT	270.0 DEG	35.0 FT/SEC
30000 - 40000 FT	270.0 DEG	60.0 FT/SEC
40000 - 50000 FT	270.0 DEG	50.0 FT/SEC
50000 - 60000 FT	270.0 DEG	40.0 FT/SEC
60000 - 70000 FT	270.0 DEG	25.0 FT/SEC
70000 - 80000 FT	270.0 DEG	20.0 FT/SEC
80000 - 90000 FT	270.0 DEG	25.0 FT/SEC
90000 - 100000 FT	270.0 DEG	25.0 FT/SEC
100000 - 110000 FT	270.0 DEG	30.0 FT/SEC

MISSION FAILURE RATE	.09
PERCENTAGE FAILURES DURING ASCENT	.40
NUMBER OF ALTITUDE CLASSES	9

ALTITUDE DISTRIBUTION OF FAILURES

0. - 12000. FT	.040
12000. - 24000. FT	.040

24000. - 36000. FT	.170
36000. - 48000. FT	.130
48000. - 60000. FT	.210
60000. - 72000. FT	.170
72000. - 86000. FT	.130
86000. - 100000. FT	.080
100000. - 114000. FT	.040

TOTAL POPULATION ASCENT AREA	202447.
TOTAL AREA ASCENT AREA (MI2)	7285.0
POPULATION GROWTH FACTOR	1.18
COMPLETELY CONTROLLABLE	.50
PARTIALLY CONTROLLABLE	.46
UNCONTROLLABLE	.04
RISK MULTIPLIER	4.00

SURVEILLANCE FACTORS

DAYTIME	.75
NIGHTTIME	.70

PICKLING FACTORS

DAYTIME	.90
NIGHTTIME	.50

PERCENTAGE POPULATION OUTDOORS

DAYTIME	.50
NIGHTTIME	.05

PROBABILITY DETECT AND AVOID DESCENDING OBJECT

PAYLOAD (DAYTIME)	.90
PAYLOAD (NIGHTTIME)	.90
BALLOON (DAYTIME)	.80
BALLOON (NIGHTTIME)	.00

STRUCTUAL PROTECTION FACTORS

HEAVY PAYLOADS	.10
HEAVY BALLOONS	.95

*** OUTPUTS ***

BALLOON ASCENT RISK MODEL

SCIENTIST: BEYMA   LAUNCH DATE: JULY 1988   LAUNCH SITE: PALESTINE

COUNTY	TOWN	CE (DAY)	CE (NIGHT)	
ANDERSON	ELKHART	.395E-10	.451E-10	
ANDERSON	FRANKSTON	.994E-10	.104E-09	
ANDERSON	PALESTINE	.634E-06	.111E-05	*
ANGELINA	BURKE	.661E-13	.207E-12	
ANGELINA	DIBOLL	.125E-10	.387E-10	
ANGELINA	HUDSON	.395E-13	.125E-12	
ANGELINA	LUFKIN	.146E-14	.718E-14	
CHEROKEE	ALTO	.151E-07	.290E-07	
CHEROKEE	GALLLATIN	.349E-08	.604E-08	
CHEROKEE	JACKSONVILLE	.109E-06	.152E-06	
CHEROKEE	NEW SUMMERFIELD	.223E-08	.403E-08	
CHEROKEE	REKLAW	.897E-08	.211E-07	
CHEROKEE	RUSK	.319E-06	.627E-06	
CHEROKEE	WELLS	.291E-09	.669E-09	
FREESTONE	FAIRFIELD	.000E+00	.000E+00	
FREESTONE	KIRVIN	.000E+00	.000E+00	
FREESTONE	OAKWOOD	.000E+00	.000E+00	
FREESTONE	STREETMAN	.000E+00	.000E+00	
FREESTONE	TEAGUE	.000E+00	.000E+00	
FREESTONE	WORTHAM	.000E+00	.000E+00	
GREGG	CLARKSVILLE CITY	.000E+00	.000E+00	
GREGG	GLADEWATER	.000E+00	.000E+00	
GREGG	KILGORE	.000E+00	.000E+00	
GREGG	LIBERTY CITY	.000E+00	.000E+00	
GREGG	ROLLING MEADOWS	.000E+00	.000E+00	
GREGG	WARREN CITY	.000E+00	.000E+00	
HENDERSON	ATHENS	.000E+00	.000E+00	
HENDERSON	BERRYVILLE	.119E-12	.112E-12	
HENDERSON	BROWNSBORO	.000E+00	.000E+00	
HENDERSON	CANEY CITY	.000E+00	.000E+00	
HENDERSON	CHANDLER	.000E+00	.000E+00	
HENDERSON	COFFEE CITY	.873E-14	.809E-14	
HENDERSON	ENCHANTED OAKS	.000E+00	.000E+00	
HENDERSON	EUSTACE	.000E+00	.000E+00	
HENDERSON	GUN BARRELL CITY	.000E+00	.000E+00	
HENDERSON	MABANK	.000E+00	.000E+00	
HENDERSON	MALAKOFF CITY	.000E+00	.000E+00	
HENDERSON	MOORE STATION	.000E+00	.000E+00	
HENDERSON	MURCHISON	.000E+00	.000E+00	

HENDERSON	PAYNE SPRINGS	.000E+00	.000E+00
HENDERSON	POYNOR	.252E-14	.233E-14
HENDERSON	SEVEN POINTS	.000E+00	.000E+00
HENDERSON	STAR HARBOR	.000E+00	.000E+00
HENDERSON	TOOL	.000E+00	.000E+00
HENDERSON	TRINIDAD	.000E+00	.000E+00
HOUSTON	CROCKETT	.000E+00	.000E+00
HOUSTON	GRAPELAND	.499E-12	.468E-12
HOUSTON	KENNARD	.137E-12	.164E-12
HOUSTON	LATEXO	.180E-14	.167E-14
HOUSTON	LOVELADY	.000E+00	.000E+00
KAUFMAN	KAUFMAN	.000E+00	.000E+00
KAUFMAN	KEMP	.000E+00	.000E+00
KAUFMAN	OAK GROVE	.000E+00	.000E+00
KAUFMAN	OAK RIDGE	.000E+00	.000E+00
KAUFMAN	POST OAK BEND CI	.000E+00	.000E+00
KAUFMAN	TERRELL	.000E+00	.000E+00
LEON	BUFFALO	.000E+00	.000E+00
LEON	CENTERVILLE	.000E+00	.000E+00
LEON	JEWETT	.000E+00	.000E+00
LEON	LEONA	.000E+00	.000E+00
LEON	MARQUEZ	.000E+00	.000E+00
LEON	NORMANGEE	.000E+00	.000E+00
LIMESTONE	COOLIDGE	.000E+00	.000E+00
LIMESTONE	GROESBECK	.000E+00	.000E+00
LIMESTONE	KOSSE	.000E+00	.000E+00
LIMESTONE	MEXIA	.000E+00	.000E+00
LIMESTONE	TEHUACANA	.000E+00	.000E+00
LIMESTONE	THORNTON	.000E+00	.000E+00
MADISON	MADISONVILLE	.000E+00	.000E+00
NACOGDOCHES	APPLEBY	.170E-09	.741E-09
NACOGDOCHES	CUSHING	.853E-08	.253E-07
NAVARRO	ANGUS	.000E+00	.000E+00
NAVARRO	BARRY	.000E+00	.000E+00
NAVARRO	BLOOMING GROVE	.000E+00	.000E+00
NAVARRO	CORSICANA	.000E+00	.000E+00
NAVARRO	DAWSON	.000E+00	.000E+00
NAVARRO	EMHOUSE	.000E+00	.000E+00
NAVARRO	FROST	.000E+00	.000E+00
NAVARRO	GOODLOW	.000E+00	.000E+00
NAVARRO	KERENS	.000E+00	.000E+00
NAVARRO	MUSTANG	.000E+00	.000E+00
NAVARRO	POWELL	.000E+00	.000E+00
NAVARRO	RETREAT	.000E+00	.000E+00
NAVARRO	RICE	.000E+00	.000E+00
NAVARRO	RICHLAND	.000E+00	.000E+00
RUSK	HENDERSON	.108E-09	.330E-09
RUSK	MOUNT ENTERPRISE	.354E-08	.104E-07
RUSK	OVERTON	.428E-13	.806E-13
SMITH	ARP	.448E-12	.731E-12
SMITH	BULLARD	.217E-11	.220E-11

SMITH	LINDALE	.000E+00	.000E+00
SMITH	NEW CHAPEL HILL	.134E-14	.124E-14
SMITH	TROUP	.265E-10	.351E-10
SMITH	TYLER	.000E+00	.000E+00
SMITH	WIITEHOUSE	.311E-12	.346E-12
SMITH	WINONA	.000E+00	.000E+00
TRINITY	GROVETON	.000E+00	.000E+00
TRINITY	TRINITY	.000E+00	.000E+00
UPSHUR	BIG SANDY	.000E+00	.000E+00
VAN ZANDT	CANTON	.000E+00	.000E+00
VAN ZANDT	EDGEWOOD	.000E+00	.000E+00
VAN ZANDT	EDOM	.000E+00	.000E+00
VAN ZANDT	FRUITVALE	.000E+00	.000E+00
VAN ZANDT	GRAND SALINE	.000E+00	.000E+00
VAN ZANDT	VAN	.000E+00	.000E+00
VAN ZANDT	WILLS POINT	.000E+00	.000E+00
WOOD	HAWKINS	.000E+00	.000E+00
WOOD	MINEOLA	.000E+00	.000E+00
TOTAL TOWN CE		.110E-05	.198E-05
RESIDUAL CE		.300E-06	.607E-06
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TOTAL CE		.140E-05	.259E-05

* MAXIMUM RISK TOWN

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