NASA TECHNICAL NOTE

NASA TN D-5120

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NASA TN D-5120

EFFECTS OF CLOUD COVER ON SELECTION OF RECOVERY SITES FOR FUTURE EARTH ORBITAL MISSIONS

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1969

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EFFECTS OF CLOUD COVER ON SELECTION OF RECOVERY SITES FOR FUTURE EARTH ORBITAL MISSIONS*

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SUMMARY

Climatological summaries are shown to be very useful as a site-selection constraint. Increased maneuverability of the entry vehicle greatly improves the probability of acquiring a site with clear weather during recovery. A possible global recovery network has been proposed which can be considered as a nucleus for most future earth orbital recovery operations. This analysis has been based on climatological summaries of the probability of 3/10 or less cloud cover. Consideration of the other meteorological factors of importance was beyond the scope of this study. However, a cursory analysis of other weather conditions at the sites, such as surface winds, ceiling height, gusts, and air turbulence, has indicated that no particular conditions might be expected which would rule out any of the recommended recovery sites from future consideration.

INTRODUCTION

Of the possible space missions that might be undertaken in the future, manned space stations, because of their wide versatility in both civilian and military applications, appear especially likely. Efficient utilization of the space station concept will require frequent logistic flights with dependable land-recovery techniques. While normal operational procedure might be to accept the wait time in orbit necessary for return to the prime United States recovery site, safety constraints can be expected to require recovery networks established on a global basis to provide rapid response to unforeseen emergencies. Furthermore, emergency conditions may require "quick" return capability (i.e., the time lapse between the decision to return and the initiation of the return maneuver is less than one orbital period).

One aspect of the orbital recovery problem which has received little attention in the literature is the influence of weather on the probability of safe recovery. Weather conditions during landing have been a problem of major concern for over 60 years of

*This material was presented in less detail at the Third National Conference on Aerospace Meteorology, New Orleans, La., May 1968.

conventional aircraft operation. For orbital return, a recovery site must be selected prior to deorbit, and landing at this site must be accomplished after retrofiring is completed. Therefore, it is important to have a network of recovery sites selected so that there is a high probability of acceptable weather conditions during recovery.

The influence of the meteorological environment on the operational aspects of recovery of lifting entry vehicles has been treated in reference 1. The current paper analyzes the effects of one portion of the meteorological environment – cloud cover – on selection of recovery sites for future earth orbital recovery operations. Since direct solution of the all-weather recovery problem is improbable, the indirect method of avoiding bad weather environment is necessary. Examples of the effectiveness of two means of avoiding undesirable weather environment are presented; first, by selection of sites based on climatological summaries,* and second, by increasing the maneuverability of the entry vehicle. The purpose of this study is to prove the feasibility of establishing a global network to support the recovery of a wide variety of entry vehicles returning from any orbit inclination. The recovery networks thus proposed should be considered as a nucleus for future, more detailed, studies intended to finalize site selection prior to the actual establishment of the global network.

ASSUMPTIONS AND CONSTRAINTS

Site Selection

The sites considered are restricted to prepared airstrips with runways at least 8000 feet (2440 meters) long on which aircraft (commercial and/or military) of the United States are currently permitted to land. A list of 865 acceptable sites is given in reference 2. The accessibility analysis of reference 3 for a wide range of entry vehicles and orbit inclinations was used to reduce the total number of sites considered herein to 120, most of which are included in table II of reference 3.

For the present analysis, clear weather has been defined as 3/10 or less cloud cover (i.e., for >3/10 cloud cover, an instrumented landing is assumed to be necessary). This cloudiness criterion was considered a reasonable compromise between the conditions desired and those likely to occur, and data were available at the time this analysis was conducted for most of the recovery sites considered. It should be emphasized that this condition is used only as a site selection index and does not imply that entry vehicles could not land safely under more adverse conditions.

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*The author gratefully acknowledges the cooperation and contributions of Messrs. Richard A. Brintzenhofe and James Cox of the Suitland Section, Spaceflight Meteorology Group, U.S. Weather Bureau, ESSA, in providing the long-term climatological summaries which made this analysis possible.

The climatological summaries employed in this analysis consisted of the monthly probability of ≦3/10 cloud cover at each of the recovery sites. This information was initially used to reduce further the number of candidate recovery sites by dropping from consideration those sites with inherent local cloudiness such as the examples listed in table I. Throughout the analysis, sites with an average yearly probability of ≦3/10 cloud

TABLE I.- TYPICAL SITES DROPPED FROM CONSIDERATION

BECAUSE OF INHERENT LOCAL CLOUDINESS

Site	Percent probability of ≦3/10 cloud cover											
	J	F	M	A	M	J	J	A	S	O	N	D
Juneau, Alaska	19	14	16	10	13	13	10	13	10	10	10	10
Anderson AFB, Guam	12	13	12	16	15	13	9	5	6	8	12	12
Arivonimamo, Malagasy Republic	0	0	0	0	3	3	0	10	7	7	3	0

cover below 40 percent were considered only for those return situations in which the vehicle could reach no other site with a higher probability of clear weather.

Analysis Technique

The analysis technique used in this study is the same as that developed in reference 4. Essentially the objective is to select a recovery network (consisting of the minimum number of recovery sites) that will meet all the assumed mission requirements for a given entry vehicle. The additional constraint of maximizing the probability of acquiring a recovery site with clear weather during landing restricts the selection considerably, as illustrated in table I. This constraint generally requires a larger number of sites located at lower latitudes, as will be illustrated subsequently.

The problem then consists of using the list of acceptable sites, with the additional criterion of probability of ≦3/10 cloud cover, to select a recovery network that will meet all the mission requirements with a reasonable number of sites. (Obviously, an infinite number of sites would maximize the probability of acquiring a site with clear weather during landing.)

Combination of Probabilities

With a given recovery network and vehicle ranging capability, the vehicle will sometimes have a choice of two or more recovery sites which can be reached during a given orbit. In order to combine the probability of ≦3/10 cloud cover in these cases, the weather conditions at one site must be considered to be independent of those at other sites. In this study, it has been assumed that independence of weather conditions at two sites is assured if these sites are at least 1800 nautical miles apart. In this case, the probability of acquiring a site with clear weather during recovery is given by

$$P = P_1 + P_2 - P_1 P_2 \tag{1}$$

where the subscripts 1 and 2 refer to sites 1 and 2. If the sites are separated by less than 1800 nautical miles, the probability of acquiring a site with clear weather during recovery is either P_1 or P_2, whichever is the greater.

Delay Orbits

It should be emphasized here that permitting delay orbits would significantly improve the probability of clear weather during recovery. Delay orbits are not considered in this study for two reasons: (1) the probabilities would increase rapidly with increasing permissible wait time in orbit so that the comparisons would be meaningless, and (2) the premise of a global recovery network presupposes return during emergencies, for which an accurate prediction of permissible wait time in orbit is impossible.

EXAMPLES OF UTILIZATION OF CLIMATOLOGICAL SUMMARIES IN RECOVERY-SITE SELECTION

Seasonal Weather Variation

Limitations of a vehicle's range capability or special mission requirements may sometimes necessitate the use of recovery sites with large seasonal weather variations. Since manned space stations may have lifetimes exceeding a year, these recovery sites could be required during any season. Climatological summaries in terms of monthly probability of clear weather make it possible to select two or more recovery sites which a given vehicle can reach during a particular orbital period so that large seasonal variations of weather are neutralized, as illustrated in figure 1.

A vehicle with lift-drag ratio (L/D) of approximately 1.2 can reach both Brownsville, Texas, and Kimpo, South Korea, during the same orbit daily for return from a 60° orbit inclination. Both sites have rather marked seasonal variation in cloudiness. However, the addition of Kimpo as an alternate site to Brownsville neutralizes the large seasonal variation for both sites, and increases the probability that at least one site will have clear weather to generally greater than 60 percent.

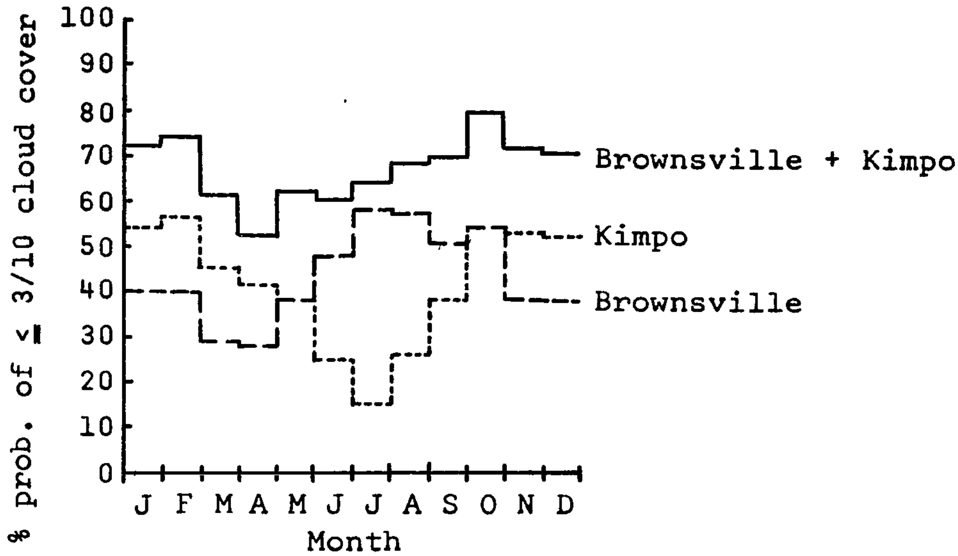


Figure 1.- Selection of sites to neutralize large seasonal weather variations.

Effects of Site-Selection Constraints

Analyses of space station missions have indicated that orbital inclinations greater than 50° are desirable to obtain significant benefits in earth-oriented research. The inclination selected for this example is 60°.

Previous recovery-network selections generally have been based primarily on geopolitical constraints (for example, refs. 2 and 3). That is, the sites selected are so located geographically as to offer a maximum number of return opportunities daily to the entry vehicle and lie within countries friendly to the United States. Consider an $L/D \approx 1.2$ vehicle (lateral range capability of 800 nautical miles) in a 60° low-altitude orbit with a mission requiring "quick" return capability. Under the customary geopolitical selection constraints with the additional restriction of minimizing the total number of sites required for the recovery operation, a four-site network might be selected as shown in table II.

The recovery-site latitude which will maximize the number of return opportunities from the orbital mechanics analysis for the $L/D \approx 1.2$ vehicle in a 60° orbit is 46.7° (see ref. 5). The latitudes of Spokane, Shema, and Laarbruck are 47.6°, 52.7°, and 51.6°, respectively. These sites thus offer excellent return accessibility; they allow return from 15 of 16 orbits daily so that the fourth site, Kimpo, is needed only for one orbit in order to meet the quick-return requirement. The yearly average probability of $\leq 3/10$ cloud cover is also listed in table II, however, and it can be easily seen that this group of sites, particularly Shema, could have a hazardous meteorological environment during the recovery operation.

The climatological summaries used in this study indicate that significant increases in probability of clear weather can be obtained only by selecting sites that are at considerably lower latitudes than the optimum value for this mission. Deviating from the optimum latitude reduces the number of opportunities for return to a single site, and thus requires an increase in the total number of sites within the recovery network that will meet the quick-return requirement. From a planning viewpoint, the penalty of more sites within the recovery network is accepted, and then sites are selected which will maximize the probability of acquiring a site with clear weather during recovery. Networks containing a total of five sites and six sites have been selected independently, considering both weather and geopolitical constraints, and are listed in tables III and IV (these networks represent the best combination from the weather viewpoint available within the 120 sites considered which will meet all of the mission constraints). The yearly average probabilities of clear weather for the five-site and six-site networks are compared with that for the four-site geopolitical network in figures 2(a) and 2(b), respectively, for each orbit daily.

TABLE II.- FOUR-SITE GEOPOLITICAL NETWORK (SELECTED WITHOUT REGARD TO WEATHER)*

Recovery site	Latitude	Yearly prob. of ≦3/10 cloud cover, percent	Orbit number															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Spokane, Washington	47.6° N	35	X	X	X	X	X										X	X
Shema, Aleutian Isl.	52.7° N	7		X	X	X	X	X	X	X								
Laarbruck, W. Germany	51.6° N	23										X	X	X	X	X	X	
Kimpo, South Korea	37.6° N	40				X	X				X	X						

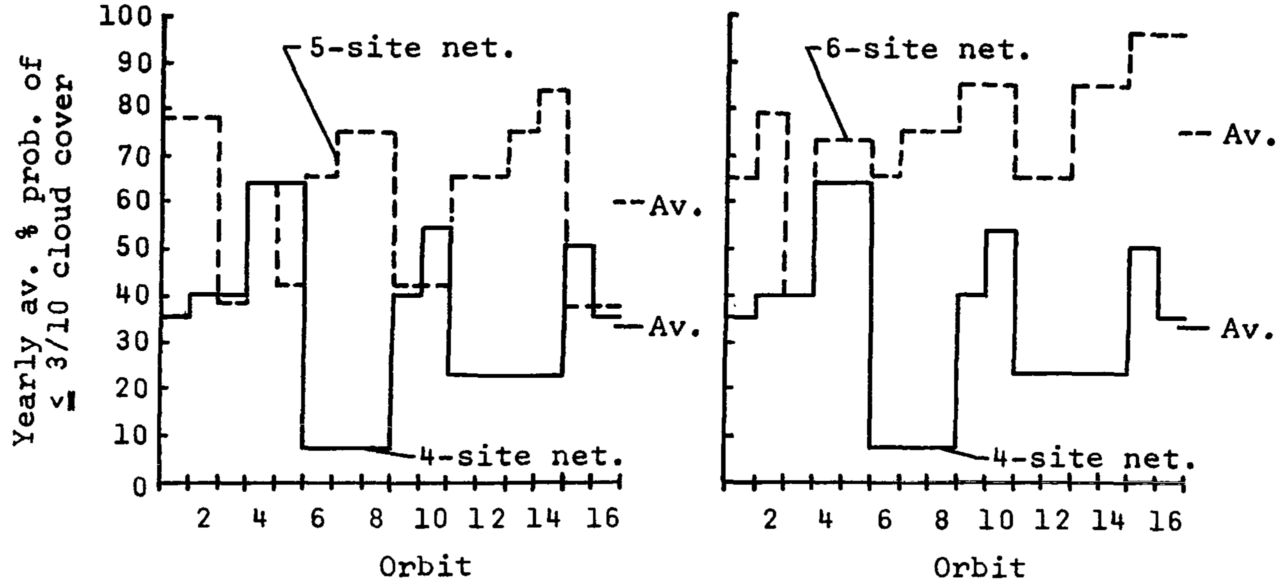
*The ability to return during a particular orbit for a spacecraft completing 16 orbits daily is indicated by an X.

TABLE III.- FIVE-SITE WEATHER + GEOPOLITICAL NETWORK

Recovery site	Latitude	Yearly prob. of ≦3/10 cloud cover, percent	Orbit number															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Grand Forks, N. D.	48° N	38	X	X	X	X										X	X	X
Alice Springs, Australia	23.8° S	65	X	X									X					
Moron, Argentina	34.7° S	42				X	X				X	X						
Dhahran, Saudi Arabia	26.3° N	75							X	X					X	X		
Ambala, India	30.4° N	65						X	X					X	X			

TABLE IV.- SIX-SITE WEATHER + GEOPOLITICAL NETWORK

Recovery site	Latitude	Yearly prob. of ≦3/10 cloud cover, percent	Orbit number															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Edwards AFB, Calif.	34.9° N	73				X	X										X	X
Langley AFB, Va.	37.1° N	40		X	X										X	X		
Alice Springs, Australia	23.8° S	65	X	X									X					
Reggan, Algeria	26.7° N	85									X	X					X	X
Dhahran, Saudi Arabia	26.3° N	75							X	X					X	X		
Ambala, India	30.4° N	65						X	X					X	X			



(a) Comparison of four-site geopolitical and five-site weather + geopolitical networks.

(b) Comparison of four-site geopolitical and six-site weather + geopolitical networks.

Figure 2.- Effectiveness of site selection based on climatological summaries in addition to geopolitical considerations in improving the probability of clear weather during recovery.

The reduced number of daily opportunities for return to a given site in tables III and IV as compared with the four-site geopolitical network of table II gives an indication of the penalty associated with deviating from the optimum latitude. The average yearly probability of clear weather also listed in tables III and IV, however, illustrates the gains possible in the probability of clear weather when selecting sites at lower latitudes. The overall average probability of clear weather is indicated at the right-hand edge of figures 2(a) and 2(b). A vehicle returning to the four-site network selected solely from geopolitical considerations would have a probability of acquiring a site with clear weather in only 33 percent of the return opportunities, while the same vehicle would have an average probability of 60 or 75 percent in returning to the five- or six-site network, respectively.

EFFECTS OF INCREASING RANGE CAPABILITY

The influence of range capability on both return opportunity and site selection is illustrated schematically in figure 3. The site to which the $L/D \approx 0.5$ vehicle (lateral range capability of 210 n. mi.) would probably return is Moron, Argentina, for the particular orbit chosen. The higher performance $L/D \approx 1.2$ vehicle can reach Edwards AFB and Kimpo, South Korea, in addition to Moron. The advantages of maneuverability lie not only in the capability of reaching more sites, but also in that sites with more desirable weather environment can be included in the recovery network, as illustrated by table V.

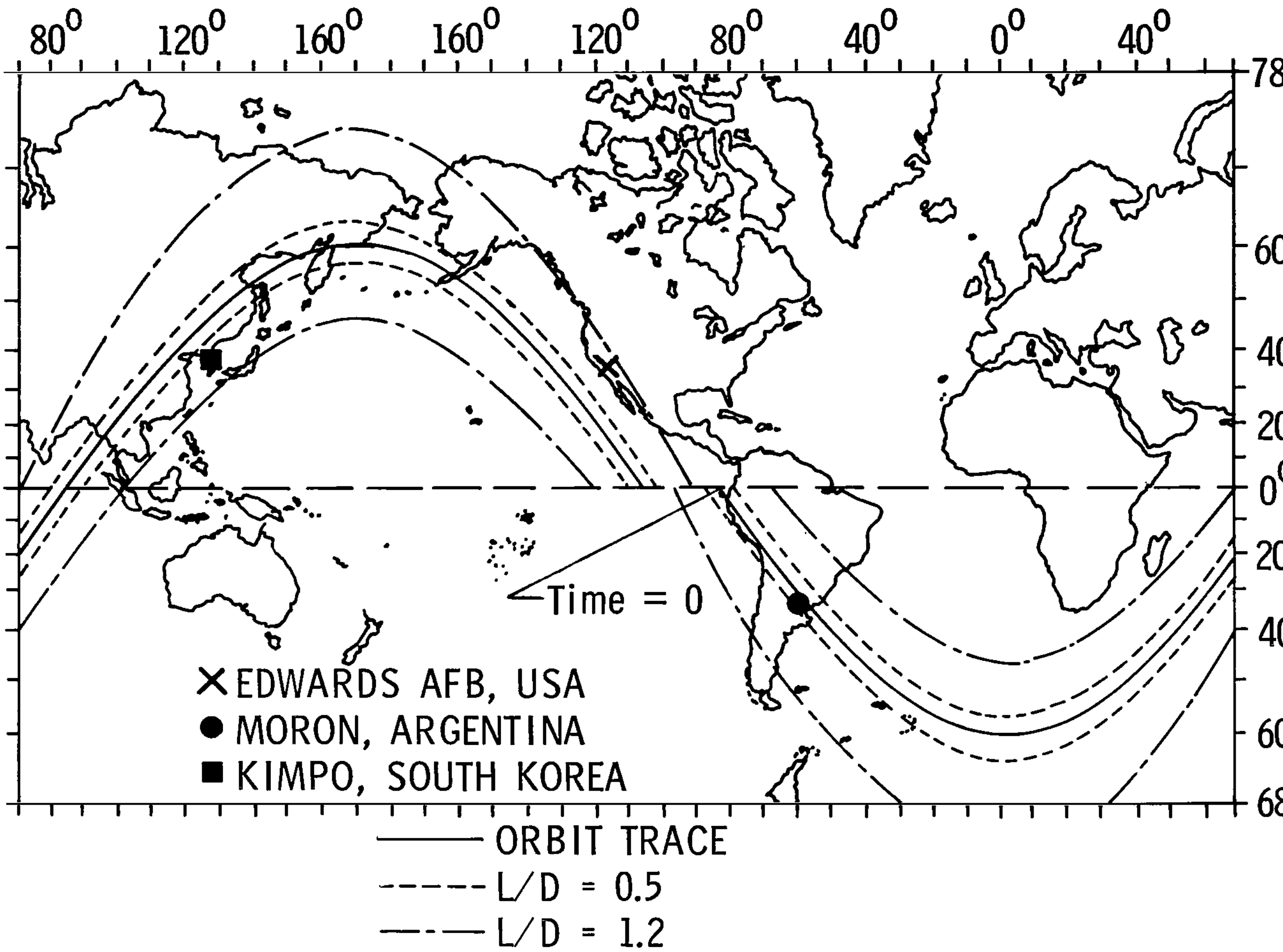


Figure 3.- Example of the effects of maneuverability on site selection for orbital return.

TABLE V.- COMPARATIVE MONTHLY PROBABILITY OF CLEAR WEATHER

FOR EDWARDS AFB, CALIF., AND MORON, ARGENTINA

Site	Percent probability of ≤3/10 cloud cover											
	J	F	M	A	M	J	J	A	S	O	N	D
Edwards AFB, Calif.	52	61	60	66	76	88	85	87	88	79	71	62
Moron, Argentina	53	55	48	52	32	26	32	38	38	39	45	48

In a further analysis of the effects of vehicle range capability on the probability of acquiring a site with clear weather during recovery, a semiballistic vehicle with $L/D \approx 0.5$ is considered as the reference vehicle. This vehicle would be capable of quick return from a 60° orbit to a 10-site network under ideal conditions. That is, because of the limited maneuverability of this vehicle, the assumption that the orbit passes over a fixed point on earth every 24 hours simplifies the analysis by reducing the total number of recovery sites that must be included in the network, and the initial time reference must be fixed to a relatively narrow time band in order to achieve quick return alinement with the 10-site network. If these two time restrictions are removed, recovery areas must be of very large diameter or a larger total number of sites must be considered for this vehicle.

The return of the reference vehicle to the reference 10-site network is compared in figure 4 with the return of the higher performance $L/D \approx 1.2$ vehicle to networks defined as follows (and listed in table VI):

(a) The 10-site network required for the reference vehicle. This comparison illustrates the advantages of increased maneuverability in reaching more sites during most orbits (see fig. 4(a)).

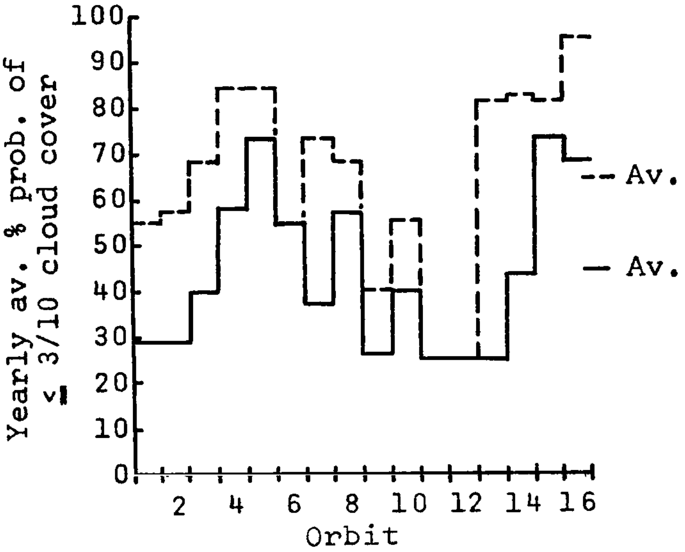
(b) The six-site network selected for quick return of the $L/D \approx 1.2$ vehicle. This comparison illustrates the advantages of increased maneuverability in that the total number of sites can be reduced and more desirable sites can be selected so that an overall increase in probability of clear weather can be realized (see fig. 4(b)).

(c) A 10-site network selected specifically for the $L/D \approx 1.2$ vehicle. This example illustrates the maximum increases in probability of clear weather available for the higher performance vehicle without the penalty of using more sites than are required for the reference vehicle (see fig. 4(c)).

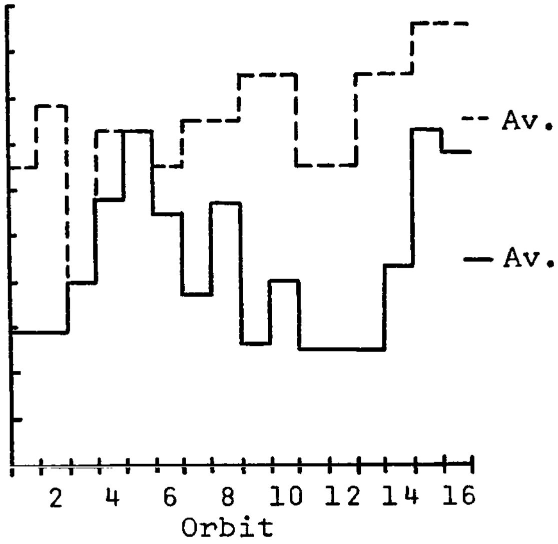
TABLE VI.- NETWORKS SELECTED TO ILLUSTRATE BENEFITS

OF INCREASED RANGING CAPABILITY

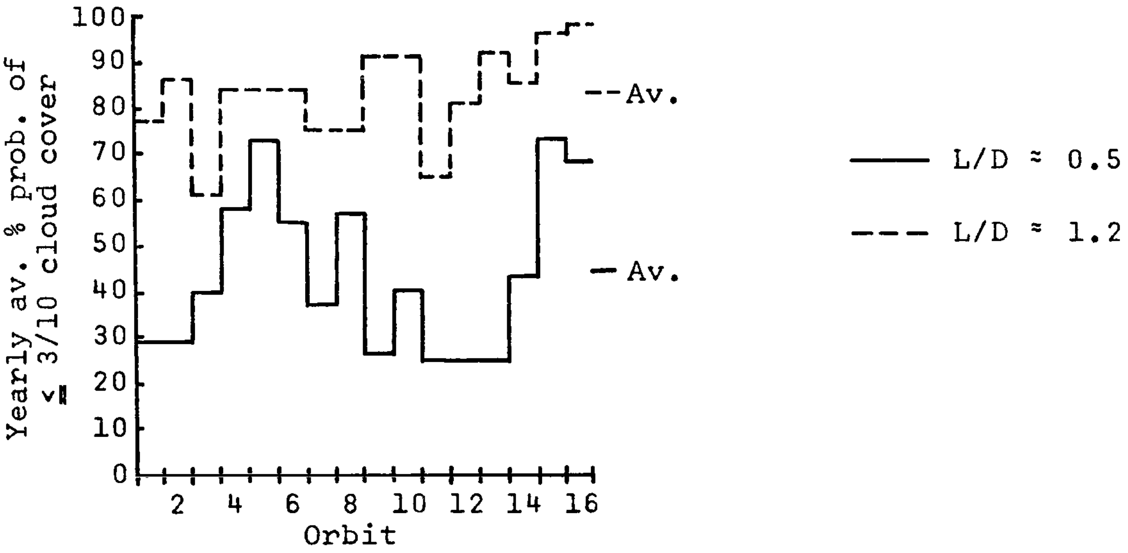
Reference 10-site network ($L/D \approx 0.5$)	6-site network for $L/D \approx 1.2$	10-site network for $L/D \approx 1.2$
1. Edwards AFB, Calif.	1. Edwards AFB, Calif.	1. Edwards AFB, Calif.
2. Langley AFB, Va.	2. Langley AFB, Va.	2. Langley AFB, Va.
3. Brownsville, Texas	3. Alice Springs, Australia	3. Alice Springs, Australia
4. Hickam AFB, Hawaii	4. Reggan, Algeria	4. Reggan, Algeria
5. Churchill, Canada	5. Dhahran, Saudi Arabia	5. Dhahran, Saudia Arabia
6. Chitose, Japan	6. Ambala, India	6. Ambala, India
7. Kimpo, South Korea		7. Spokane, Washington
8. Stockholm, Sweden		8. Moron, Argentina
9. Gertzog, South Africa		9. Perth, Australia
10. Tehran, Iran		10. Gertzog, South Africa



(a) Return of both vehicles to reference 10-site network.



(b) Return of reference vehicle to reference network and L/D ≈ 1.2 vehicle to six-site network.



(c) Return of reference vehicle to reference network and L/D ≈ 1.2 vehicle to 10-site network.

Figure 4.- Effects of range capability on probability of clear weather during recovery.

The average values at the right of figure 4(a) show that the $L/D \approx 1.2$ vehicle has higher probability of acquiring a site with clear weather in return to the reference 10-site network by a factor of 1.5 over that for the reference vehicle. Similarly, the $L/D \approx 1.2$ vehicle has a higher probability in return to its six-site network by a factor of 1.7 over that for the reference vehicle returning to the reference network (see fig. 4(b)). Maximum utilization of the increased range capability of the higher performance vehicle almost doubles the probability of acquiring a site with clear weather during recovery that is achievable by the reference system (see fig. 4(c)).

POSSIBLE SITES FOR FUTURE RECOVERY NETWORK NUCLEUS

The examples in the preceding sections have shown that there are sufficient acceptable global sites with a relatively high probability of clear weather to serve as sites within recovery networks for return from several missions in a 60° orbit. From considerations of economy, the question that remains to be answered is, Is it feasible to establish a single global recovery network to serve a wide variety of vehicles returning from any orbit inclination of interest?

Network Generation

In order to answer this question, 25 recovery networks were selected (by the approach used in the previous section) with the consideration of climatological summaries as a constraint to determine whether certain sites recurred more frequently than others. These networks were based on the following postulated mission recovery requirements:

(1) Quick return of semiballistic vehicle ($L/D \approx 0.5$)

(2) Quick return of $L/D \approx 1.2$ vehicle

(3) Quick return of $L/D \approx 1.2$ vehicle with choice of at least two sites at least 1800 nautical miles apart during each orbit

(4) Quick return of $L/D \approx 3.0$ vehicle (lateral range capability of 3600 n. mi.)

(5) Quick return of $L/D \approx 3.0$ vehicle with choice of at least two sites at least 1800 nautical miles apart during each orbit

For each of the above constraints, returns from orbit inclinations of 30°, 45°, 60°, 75°, and 90° were considered. Because of the symmetry in lateral range requirements, this selection of orbit inclinations represents an actual range of 30° to 150°. The broad range of orbit inclinations and classes of entry vehicles considered makes the results applicable to stringent requirements for almost any future earth orbital operation.

Preferred Sites

In the 25 recovery networks generated, four sites were selected for at least 40% of the networks, and an additional seven sites were selected for at least 24% of the networks. These sites are listed in table VII in order of their recurrence. The locations and the monthly climatological summaries of these sites are also included. The global distribution of these sites is shown in figure 5. It is important to realize that these sites are not recommended as exact landing locations, but rather as localized geographical areas. The fact that these sites are distributed longitudinally so that excellent accessibility is provided to the returning vehicle, coupled with the near maximum probability of clear weather resulting from the site selection process, points out the feasibility of establishing a recovery network nucleus to serve a broad spectrum of future space missions.

Return-Parameter Variation for Preferred Sites

To illustrate the effectiveness of these recovery networks, two orbital return parameters which are of particular interest – the maximum wait time in orbit and the number of return opportunities per day – will be considered. For these examples, an orbital period of 1.5 hours has been assumed, resulting in 16 orbits per day. A random initial location of the vehicles on their orbits has been assumed to maintain the generality of the analysis. The variations of these orbital parameters with orbit inclination for the vehicles analyzed are shown in figure 6 for the basic four-site and the 11-site networks.

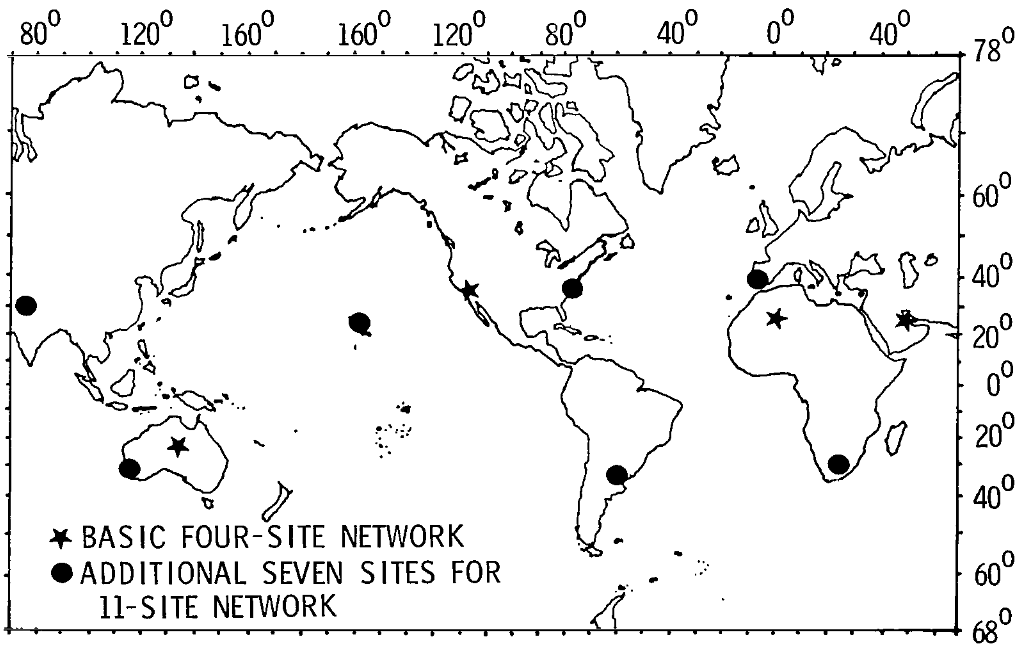
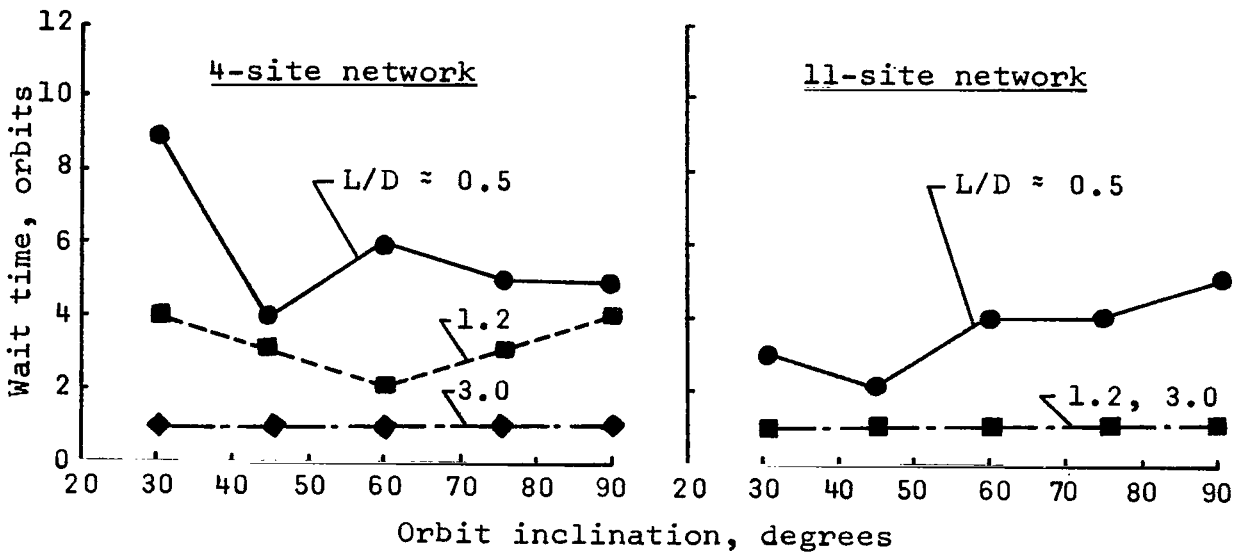


Figure 5.- Global distribution of sites.

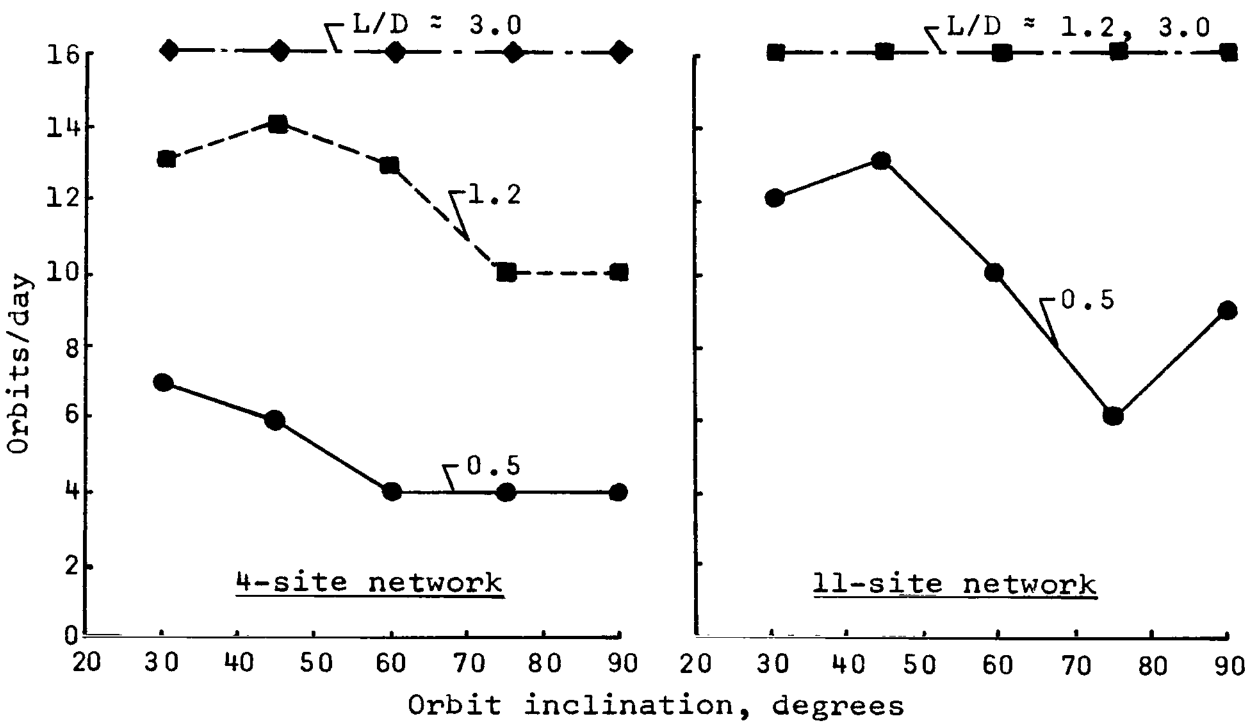
TABLE VII.- LOCATION AND CLIMATOLOGICAL SUMMARIES OF PREFERRED SITES

Site	Latitude	Longitude	Percent probability of ≦3/10 cloud cover												Length of record	Time of observation
			J	F	M	A	M	J	J	A	S	O	N	D		
Basic four-site network																
Edwards AFB, Calif.	34°54' N	117°52' W	52	61	60	66	76	88	85	87	88	79	71	62	23 yr	Hourly
Dhahran, Saudi Arabia	26°16' N	50°10' E	67	60	50	60	74	88	83	88	96	95	75	61	10 yr	Unavailable
Alice Springs, Australia	23°48' S	133°53' E	60	56	64	66	56	65	72	81	81	64	60	52	10 yr	6, 12, 18
Reggan, Algeria	26°41' N	0°17' E	90	85	90	84	80	79	89	87	80	76	66	85	4-5 yr	7, 13, 18
Additional seven sites for 11-site network																
Ambala, India	30°22' N	76°50' E	66	69	66	69	78	73	30	38	50	87	88	68	4-10 yr	3-hr intervals*
Langley AFB, Va.	37°05' N	76°22' W	37	39	38	37	35	35	36	37	42	47	45	44	28 yr	Hourly
Moron, Argentina	34°40' S	58°38' W	53	55	48	52	32	26	32	38	38	39	45	48	8 yr	9, 13, 16
Perth, Australia	31°39' S	116°00' E	60	67	59	44	41	36	34	38	41	39	45	60	10 yr	6, 12, 18
Moron, Spain	37°10' N	5°36' W	35	45	32	42	47	64	88	86	66	51	42	35	5 yr	Hourly
Hickam AFB, Hawaii	21°20' N	157°55' W	41	38	38	32	33	34	38	36	45	40	38	36	25 yr	Hourly
Gertzog, South Africa	29°06' S	26°18' E	52	35	47	52	62	78	73	64	65	54	54	49	4 yr	8, 14

*Recorded at 3-hr intervals for 4-yr period and at longer intervals over 10-yr period.



(a) Maximum wait time in orbit.



(b) Return opportunities per day.

Figure 6.- Variation of orbital return parameters for the basic four-site and the 11-site network.

The $L/D \approx 0.5$ vehicle requires a maximum daily wait time of nine orbits for return to the four-site network, and five orbits for return to the 11-site network, for the worst orbit inclination. (See fig. 6(a).) This vehicle is assured of at least four opportunities daily for return to the four-site network and six opportunities daily for return to the 11-site network (See fig. 6(b).)

Increasing the maneuverability of the entry vehicle reduces wait time in orbit and increases return opportunities. For example, the $L/D \approx 1.2$ vehicle generally has equal or less wait time in orbit and equal or more opportunities for return with the four-site network than does the $L/D \approx 0.5$ vehicle with the 11-site network.

Examples of Using Basic Four-Site Nucleus

A basic recovery network consisting of the four sites indicated by stars in figure 5 can be envisioned, to which additional sites of the seven indicated by the solid circles could be added as needed to support a particular mission. As an example of this approach, a weighted analysis placing prime importance upon reducing maximum wait time in orbit has been applied for the following constraints:

(1) Addition of two landing sites to support recovery of the semiballistic vehicle from any orbit inclination (fig. 7(a)).

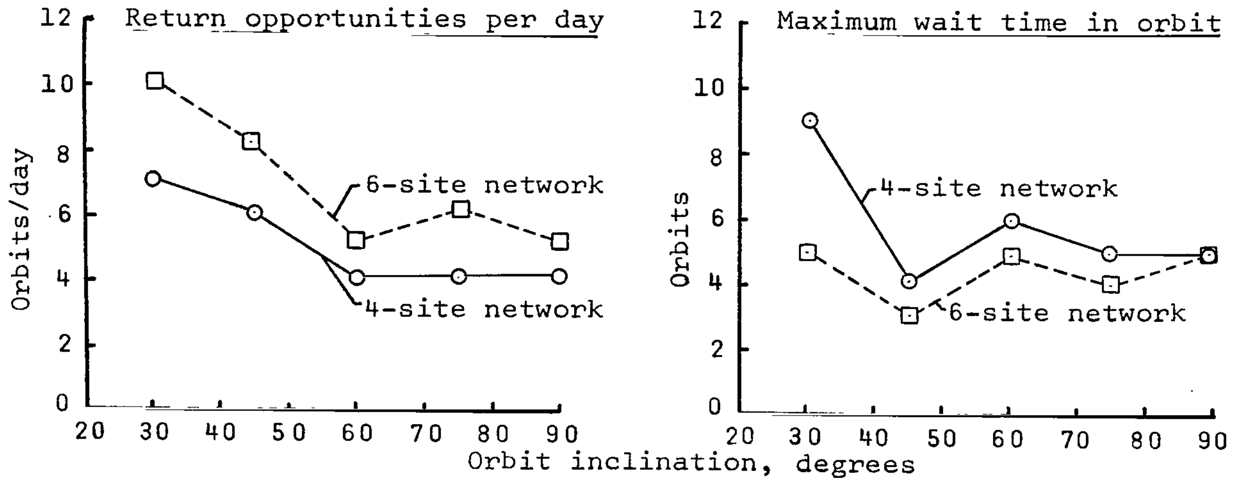
(2) Addition of one landing site to support recovery of the lifting-body vehicle ($L/D \approx 1.2$) from any orbit inclination (fig. 7(b))

For case 1, the addition of Gertzog, Republic of South Africa, and Ambala, India, would be the most effective of the seven sites considered. The additional two sites increase the number of return opportunities daily for each orbit inclination, and reduce the maximum required wait time in orbit for each inclination except the polar orbit.

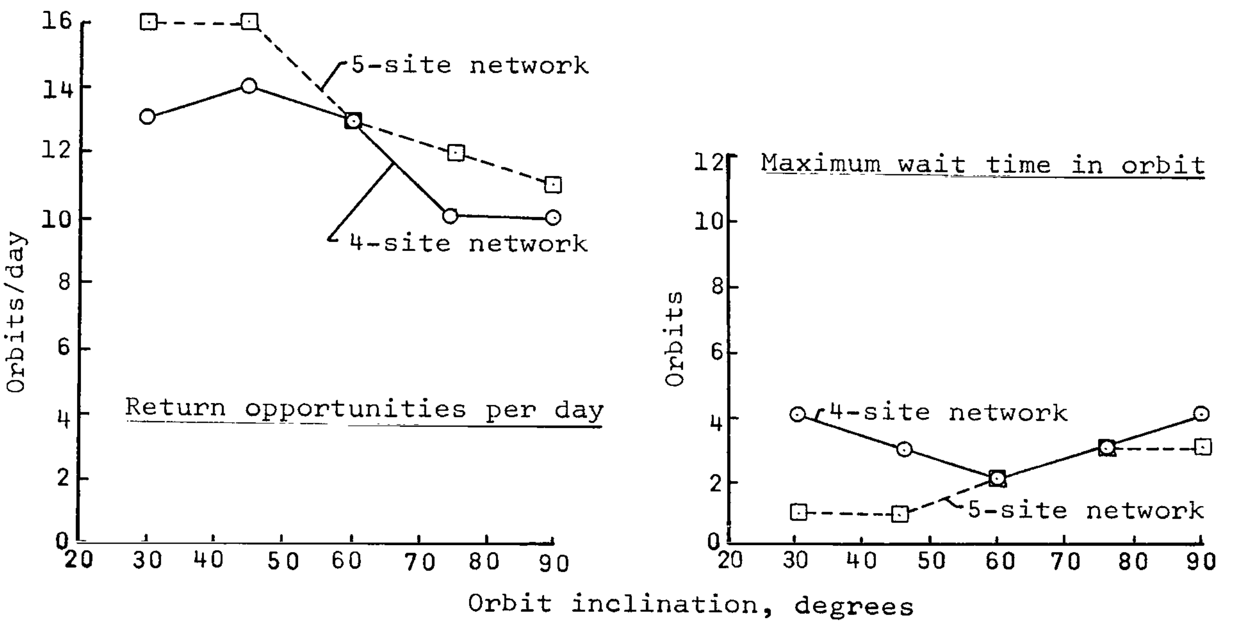
For case 2, the addition of Moron, Argentina, would be most effective. The addition of this one site increases the number of return opportunities daily for four of the five orbit inclinations, and reduces the maximum required wait time in orbit for three of the five orbit inclinations.

NEED FOR FUTURE RESEARCH

This analysis has been based on climatological summaries of the probability of 3/10 or less cloud cover. Consideration of the other meteorological factors of importance was beyond the scope of this study. However, a cursory analysis of other weather conditions at these sites, such as surface winds, ceiling height, gusts, and air turbulence, has indicated that no particular conditions might be expected which would rule out any of the



(a) Semiballistic vehicle.



(b) L/D ≈ 1.2 vehicle.

Figure 7.- Effectiveness of adding selected sites to basic four-site network.

recommended landing sites from future consideration. However, prior to the establishment of any site as a long-term recovery site, each factor of the meteorological environment should be studied in depth.

The relative importance of weather during landing as compared with other aspects of the orbital recovery problem cannot be accurately estimated as yet. The exact importance of landing-weather conditions is coupled with other questions, such as acceptable wait time in orbit and mode of landing. That is, how long is it permissible to require a crew to remain in orbit after the decision to return? If the prime U.S. landing site were not accessible because of local weather conditions, normal procedure would probably be to "wait out the storm" if no emergency requiring immediate return existed. In addition, weather conditions would not be expected to have as much influence on the successful recovery of a vehicle with auxiliary landing systems (ref. 6), such as propulsive lift or rotors, as for a lifting vehicle attempting a conventional, horizontal airstrip landing (ref. 1). Nonetheless, we can reasonably expect weather conditions during recovery to receive considerable study in preparation for future orbital operations, whatever the mission constraints.

CONCLUDING REMARKS

Climatological summaries can be used effectively in site selection to improve the probability of acquiring a site with clear weather during recovery from earth orbital missions. Increased maneuverability greatly improves the probability of acquiring a site with clear weather during recovery, not only because the higher performance vehicle can reach more sites during most orbits, but also because sites with a higher probability of clear weather can be selected for inclusion in the network. A recovery network is proposed consisting of a basic group of four global sites and an additional group of seven sites that (depending on mission requirements) can be considered as prime candidates for establishment of a single global recovery network suitable for most future orbital recovery operations.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., January 29, 1969,
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