WEATHER: ITS EFFECT ON LANDING-SITE SELECTION FOR FUTURE EARTH ORBITAL RECOVERY OPERATIONS

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INTRODUCTION

Of the possible space missions that might be undertaken in the future, manned space stations, because of their wide versatility, appear to be extremely interesting. Maximum utilization of the space station concept will require frequent logistic flights with dependable land recovery techniques. While normal operation procedure might be to accept the required wait time in orbit to return to the prime landing site, safety constraints can be expected to require recovery networks established on a global basis to provide rapid response for recovery during unforeseen emergencies. One aspect of the orbital recovery problem which cannot be solved entirely by technological advancements is that of all-weather recovery. The importance of all-weather landing in conventional aircraft operation after over 60 years of atmospheric flight indicates the extent of the problem. For orbital return in which the vehicle has considerably less low-speed maneuverability than conventional aircraft, the problem will be even more serious.

The paper presented by Zvara[1] at the preceding Conference on Aerospace Meteorology held in March of 1966 has covered the influence that the meteorological environment can have on the operational aspects of all-weather recovery of lifting entry vehicles. The purpose of the current paper is to analyze the effects of meteorological environment on landing-site selection for future earth orbital recovery operations. Since direct solution of the all-weather problem is improbable, an indirect method - that of avoiding bad weather environment - is necessary. The effectiveness of two means of avoiding undesirable weather environment - (1) selection of sites based on climatological summaries,* and (2) increasing the maneuverability of the entry vehicle - are analyzed.

For this analysis, clear weather has been defined as 3/10 or less cloud cover. This cloudiness criterion was considered a reasonable compromise between the conditions desired and those likely to occur, and was available at the time this analysis was conducted for most of the landing sites of interest. A more recent effort by the U.S. Navy will make much more detailed information available probably during this calendar year. It should be emphasized that this condition is used only as a comparative site selection index and as such does not imply that entry vehicles could not land safely under more adverse conditions.

EXAMPLES OF UTILIZATION OF CLIMATOLOGICAL SUMMARIES IN LANDING-SITE SELECTION

The climatological information employed in this analysis consisted of the monthly probability of clear weather (defined as $\leq 3/10$ cloud cover) for 120 possible landing sites distributed on a global basis.[2,3] The availability of such information initially aided in reducing the number of landing sites considered desirable for adaptation to orbital recovery operations. For example, the following sites are typical of those dropped from consideration:

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
Andersen AFB, Guam	12	13	12	16	15	13	9	5	6	8	12	12
Arivonimano, Malagasy Republic	0	0	0	0	3	3	0	10	7	7	3	0

That is, the inherent local cloudiness was considered sufficient justification to exclude these sites as candidates for routine recovery operations. Throughout the analysis, sites with yearly probability of 3/10 or less cloud cover below 40% were considered only for return situations for which the vehicle could reach no other site.

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

Seasonal Weather Variation

The climatological summaries in terms of monthly probability of clear weather also make it possible to combine landing sites which a given vehicle could reach from a given orbit, so that large seasonal variations of weather are neutralized as illustrated in figure 1. An $L/D \approx 1.2$ vehicle 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 cloudiness variation. However, the addition of Kimpo as an alternate site to Brownsville neutralizes the large seasonal variation for both sites, thus increasing the probability of clear weather to generally greater than 60 percent.

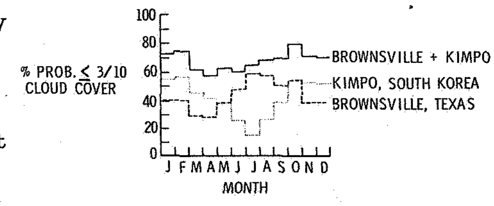

Figure 1.- Selection of sites to neutralize large seasonal weather variations.

Effects of Site Selection Constraints

Analyses of space station missions have indicated that a minimum orbital inclination of at least 50° is desirable to obtain significant benefits in earth oriented research. Previous recovery network selections generally have been based primarily on geopolitical constraints[2,3] (that is, geographical location relative to the orbital traces in terms of the accessibility of the vehicle to the site, and the consideration of only those foreign sites located in countries at which commercial and/or military aircraft of this country are permitted to land) because of the general nonavailability of global climatological summaries. As an example of the effectiveness of prior knowledge of probable weather conditions in improving the probability of clear weather during recovery, consider an $L/D \approx 1.2$ vehicle (800 nautical miles lateral ranging capability) returning from 60° low-altitude orbit to a recovery network which allows "quick"* return of the entry vehicle based on geopolitical constraints alone. A four-site recovery network might be selected consisting of Spokane, Washington; Shemya, Aleutian Islands; Laarbruck, West Germany; and Kimpo, South Korea. The consideration of weather conditions as an additional selection constraint indicates that sites such as Shemya (yearly average probability of $\leq 3/10$ cloud cover = 7%) are very undesirable even though they may have excellent geographical location for the orbital mission of interest. With the weather constraint, a five-site network consisting of Grand Forks, North Dakota; Alice Springs, Australia; Moron, Argentina; Dhahran, Saudi Arabia; and Ambala, India, would be used. If we further allow the number of sites in the network to be increased to six, a network of Edwards AFB, California; Langley AFB, Virginia; Alice Springs, Australia; Reggan, Algeria; Dhahran, Saudi Arabia; and Ambala, India, might result. Because of manuscript length limitations, the comparative probability of clear weather on return to these networks is illustrated in figure 2 for the yearly average of weather conditions. The five-site network almost doubles the probability of clear weather over that for the four-site geopolitical network, while the six-site network increases the probability by a factor of approximately $2\frac{1}{2}$ times that for the four-site network.

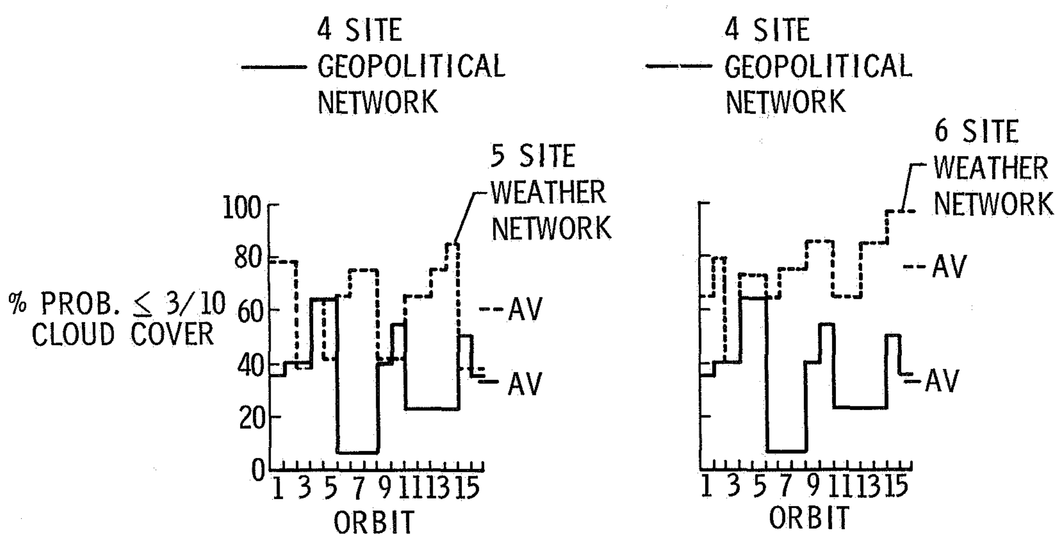

Figure 2.- Effectiveness of site selection based on climatological summaries in improving recovery weather probability.

*"Quick" return requires that the time lapse from the decision to return to the initiation of the return maneuver is less than one orbital period.

EFFECTS OF INCREASING RANGING CAPABILITY

The importance of ranging capability on both return opportunity and site selection is illustrated schematically in figure 3. The most probable site of interest to which the $L/D \approx 0.5$ (lateral range capability = 200 n. mi.) vehicle can 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 not only lie in the capability of reaching a selection of sites, but also in that sites with more desirable weather environment can be included in the recovery network as illustrated by the table below.

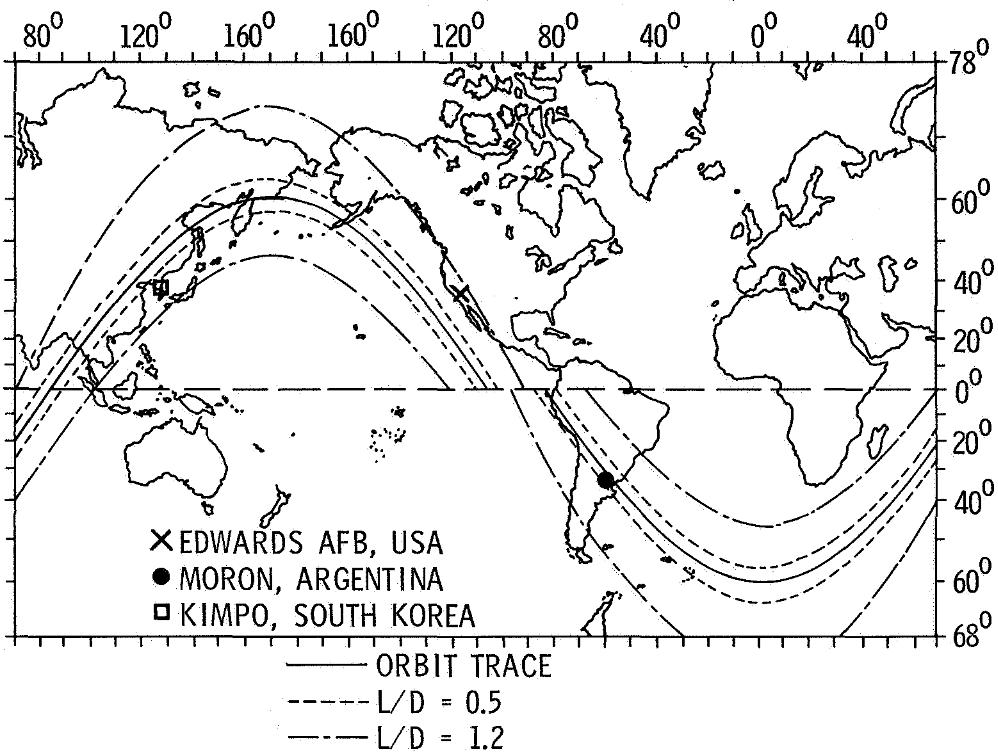

Figure 3.- Example of the effects of maneuverability on site selection for orbital return.

Site	Percent probability of $\leq 3/10$ cloud cover											
	J	F	M	A	M	J	J	A	S	O	N	D
Edwards AFB	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

To further analyze the effects of ranging capability on the probability of clear weather during recovery, consider a semiballistic vehicle with an $L/D \approx 0.5$ as the reference vehicle. This vehicle in returning from a 60° orbit would be capable of "quick" return to a ten-site network under ideal conditions. (That is, because of the limited maneuverability of this vehicle, the orbit is considered to pass over a fixed point on earth every 24 hours, and the time of injection into orbit must be fixed to a relatively narrow time band in order to achieve "quick" return alignment with the ten-site network.) Now consider the comparison of the return of the reference vehicle to the reference 10-site network with the return of the higher performance $L/D \approx 1.2$ vehicle to networks defined as follows:

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

(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 number of sites can be reduced but more desirable sites can be selected so that an overall increase in probable clear weather can be realized.

(c) A ten-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 required for the reference vehicle.

The networks thus selected are listed in the table below:

Reference ten-site network ($L/D \approx 0.5$)	Six-site ($L/D \approx 1.2$) network	Ten-site ($L/D \approx 1.2$) network
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, Tex.	3. Alice Springs, Aust.	3. Alice Springs, Aust.
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. Pearce, Australia
10. Tehran, Iran		10. Gertzog, South Africa

The comparative yearly average probabilities of clear weather during recovery for the three networks defined above are illustrated in figures 4(a), 4(b), and 4(c), respectively.

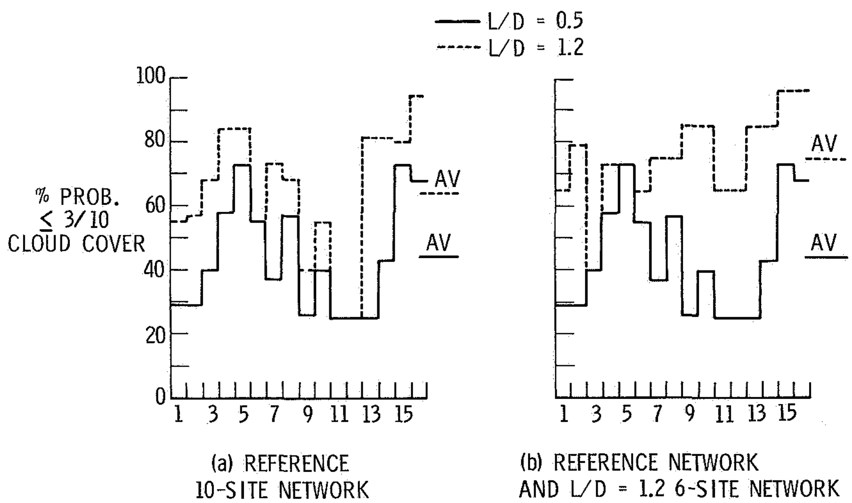

Figure 4.- Effects of ranging capability on probability of clear weather during recovery.

The $L/D \approx 1.2$ vehicle has a 50 percent higher probability of clear weather during recovery for return to the reference network than does the reference vehicle. Similarly, an increase of 70 percent results for the return of the $L/D \approx 1.2$ vehicle to its six-site network. Maximum utilization of the increased ranging capability of the higher performance vehicle results in increases of 90 percent compared with that for the reference system.

POSSIBLE SITES FOR FUTURE RECOVERY NETWORK NUCLEUS

As an exercise in recovery network selection, 25 recovery networks were generated with the consideration of climatological summaries as a constraint, to determine if 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 1800 nautical miles apart each orbit.

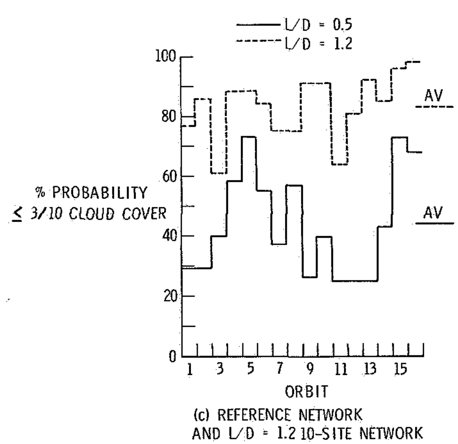

Figure 4.- Concluded.

(4) "Quick" return of $L/D \approx 3.0$ vehicle (lateral ranging capability of 3600 nautical miles).

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

For each of the above constraints, return from orbit inclinations of 30°, 45°, 60°, 75°, and 90° were considered. Because of the symmetry in lateral ranging 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. In the 25 recovery networks generated, four sites appeared at least ten times and eleven sites appeared at least six times. These sites are listed in the following table in order of their recurrence. The location of the sites and the climatological summaries of these sites are also included.

Basic Four-Site Network														
Site	Latitude	Longitude	Percent probability of ≤ 3/10 cloud cover											
			J	F	M	A	M	J	J	A	S	O	N	D
Edwards AFB, California	34°54'N	117°52'W	52	61	60	66	76	88	85	87	88	79	71	62
Dhahran, Saudi Arabia	26°16'N	50°10'E	67	60	50	60	74	88	83	88	96	95	75	61
Alice Springs, Australia	23°48'S	133°53'E	60	56	64	66	56	65	72	81	81	64	60	52
Reggan, Algeria	26°41'N	0°17'E	90	85	90	84	80	79	89	87	80	76	66	85
Additional Seven Sites for Eleven-Site Network														
Ambala, India	30°23'N	76°46'E	66	69	66	69	78	73	30	38	50	87	88	68
Langley AFB, Virginia	37°05'N	76°22'W	37	39	38	37	35	35	36	37	42	47	45	44
Moron, Argentina	34°40'S	58°38'W	53	55	48	52	32	26	32	38	38	39	45	48
Perth, Australia	31°39'S	116°00'E	60	67	59	44	41	36	34	38	41	39	45	60
Moron, Spain	37°10'N	5°36'W	35	45	32	42	47	64	88	86	66	51	42	35
Hickam AFB, Hawaii	21°20'N	157°55'W	41	38	38	32	33	34	38	36	45	40	38	36
Gertzog, South Africa	29°06'S	26°18'E	52	35	47	52	62	78	73	64	65	54	54	49

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 the establishment of a recovery network nucleus to serve a broad spectrum of future space missions.

To illustrate the effectiveness of these recovery networks, consider two orbital return parameters which are of particular interest - the maximum wait time in orbit and the number of return opportunities per day. 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 eleven-site networks.

The $L/D \approx 0.5$ vehicle has a maximum daily wait time in orbit requirement of nine orbits for return to the four-site network and five orbits for return to the eleven-site network for the worst orbit inclination. This vehicle is assured of at least four return opportunities daily to the four-site network and six return opportunities daily to the eleven-site network. The advantages of increasing the maneuverability of the entry vehicle are pointedly illustrated in figure 6.

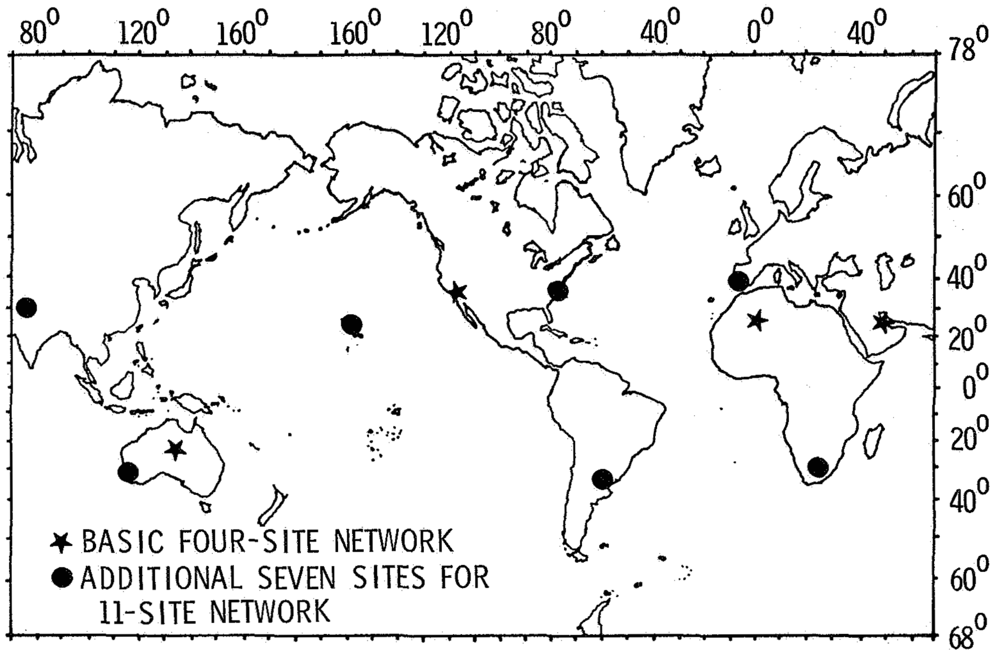

Figure 5.- Global distribution of sites.

This analysis has been based on climatological summaries of the probability of 3/10 or less cloud cover. The consideration of the other meteorological environment 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, air turbulence, etc., has indicated that no particular conditions might be expected which would rule out any of the recommended landing sites from future consideration.

CONCLUDING REMARKS

This study has indicated that climatological summaries can be used effectively in site selection to improve the probability of clear weather during recovery. Increased maneuverability has been shown to markedly improve the probability of clear weather during recovery, not only because the higher performance vehicle can reach more of the sites for most orbits, but also because sites with a higher probability of clear weather can be included in the network. An exercise in recovery network selection has indicated a basic group of four global sites and a larger group of eleven sites that (depending on mission requirements) can be considered as prime candidates for most future orbital recovery operations.

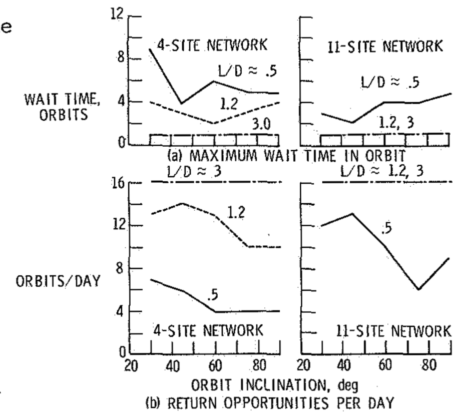

Figure 6.- Variation of orbital return parameters for the basic four-site and total eleven-site networks.

The relative importance of weather environment 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 was not accessible due to 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[4] such as propulsive lift or rotors as for a lifting vehicle attempting a conventional, horizontal airstrip landing.[1] Nonetheless, we can reasonably expect weather conditions during recovery to receive considerable study in preparation for future orbital operations whatever the mission constraints.

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