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SINGLE CAMERA STEREO/ SHUTTLE STUDY

FINAL REPORT

CDRL ITEM A006

[redacted]

(b)(1)
(b)(3) 10 USC ⊥ 424

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TECHNICAL REPORT

FOREWORD

This document contains the final report for the Single Camera Stereo/Shuttle Study. The material is presented in compliance with the requirements of [redacted] as defined in CDRL Item A006.

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STUDY OBJECTIVES

BACKGROUND

For the past few years, SP-6 has been studying the simplification of wide area search systems for collection of satellite imagery. Emphasis was placed on survivability and the reduction of the number of critical modes which resulted in system concepts employing prolification of satellite vehicles. It is generally agreed that such a prolification system must contain satellite vehicles of reduced size, weight, and volume. A major objective of these studies has been to evaluate the relative value of small SVs compared to large satellites such as HEXAGON from the standpoint of coverage, access, and survivability while exploiting STS capabilities. In the spring of 1978 SP-6 funded four camera contractors to study the use of a single camera to obtain stereo imagery for both wide area search and MC&G. These studies indicated feasibility of such a concept using a Single Camera Stereo (SCS) payload with aperture of approximately 20 in. capable of providing NIIRS-4 imagery at altitudes ranging from about 150 to 180 nm. The camera concepts incorporated existing silver-halide (1414) film with growth to photo-conductive film for near-real-time readout capability.

The SCS/Shuttle study was initiated by SP-6 in October 1978 to investigate the application of the SCS camera designs to SCS system concepts, considering evolution from early shuttle experiments to advanced technology free-flyers.

The study objectives addressed an SCS/Shuttle experiment as early as 1981 with an interim operational pallet (1983-86). The advanced technology free-flyer, i.e., photo-conductive (PC) film with near-real-time readout, was conceived for the 1986 time period and beyond.

1 EXECUTIVE SUMMARY

MAJOR RESULTS

The SCS system study indicates that SCS Shuttle Pallets could be flown as early as 1982 and that free flyers could be flown by 1984. Specific system concepts showed the following results:

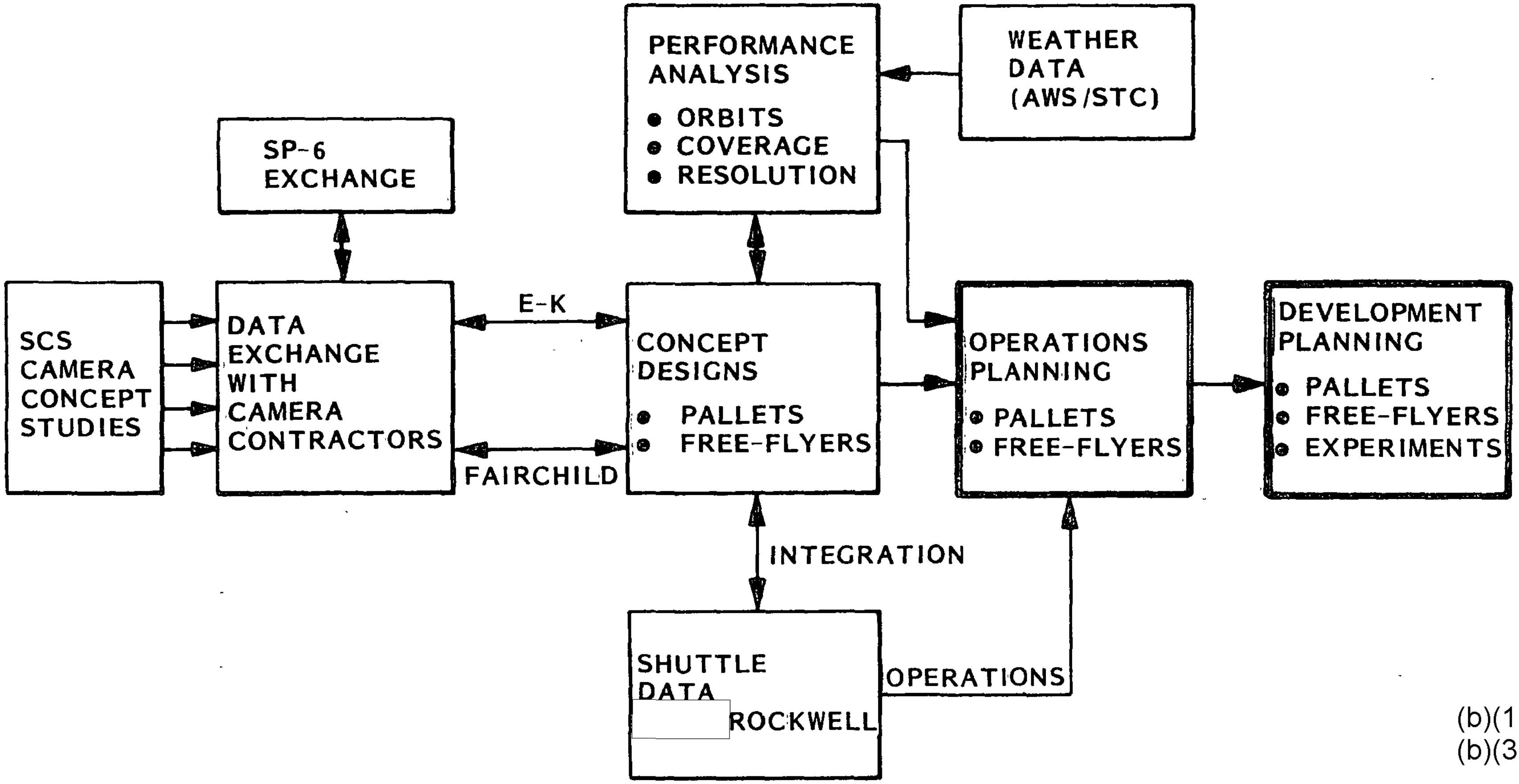
(1) ETR-Pallets (5000 lb) could operate at 159 nm circular orbits at 57° inclination for 20 days. The 20 day pallet would provide about 60% more target access than a 60 day *hexagon* in the 45° to 59° latitude band (which contains high density European targets). The increased access results from higher altitude, ascending and descending imaging and the convergence of the orbit traces in the 45° to 57° latitude band. Specifically, during the equinox period a 20 day mission provides 21 accesses to 50° latitude targets giving a probability of 0.98 of meeting *dense area* requirements. The ETR-Pallet requires about 32,500 lb (5000 lb pallet plus 27,500 lb for shuttle propellants and reactants) out of shuttle's 53,500 lb capability, leaving 21,000 lb for shared payloads. The ETR-Pallet could also support experimental development and evaluation of advanced technology concepts.

(2) WTR-Pallets (5000 lb) could be operated for about 18 days in typical 150 x 218 nm sun synchronous (97° inclination) orbit. However, they require a *dedicated launch* because the shuttle WTR payload capability into the 97° orbit is only 28,500 lb. Target access, which is slightly higher than 1/3 that of a 60 day *hexagon* mission (due to the higher altitude), is probably not adequate to justify the cost of dedicated shuttle launches.

(3) WTR-Free Flyers (8300 lb) offer an alternative to pallets. Evaluation was based on existing technology (silver halide film with shuttle retrieval). A typical mission would include two to three SVs launched from a single shuttle into a sun synchronous orbit. One concept would be to operate satellites at two altitudes: 170 nm circular to meet coverage requirements at NIIRS-4 and 130 nm for about 2 months, scheduled just before retrieval, to satisfy the 60 day requirement for NIIRS-5. A practical shuttle film retrieval interval would be about 4 months and the free-flyer offers very flexible operations with maximum opportunity for sharing the shuttle; however, a key factor may be the availability of shared (sun synch) operations for film retrieval. An optimized system with photo-conductive film and supporting advanced technology, could provide world-wide daily access with near real-time readout.

Other conclusions of the study include: (1) both shuttle-pallets and free-flyers could meet MC&G requirements with location accuracies of 25 ft (goal of 15 post pass) by 1986; (2) pallets may require more complex cameras than free-flyers, i.e., larger apertures to make up for lower average sun angles and less flexibility for part-time operation at decreased altitude.

METHODOLOGY



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METHODOLOGY

The study started with a review of the final reports of the four (ITEK, P-E, E-K and Fairchild) SCS camera contractors. We then visited each of the four contractors for detailed discussion relative to their designs. The results of these efforts were reviewed with the customer and it was concluded that we would proceed only with the E-K and Fairchild camera designs, since these designs were representative of the SCS camera concept.

The primary efforts of the study were: (1) concept designs; (2) analysis of weather data; (3) analysis of performance especially as impacted by weather statistics; (4) identification of critical shuttle interfaces.

These efforts were integrated to define both pallet and free-flyer operational concepts and represent the KEY OUTPUT of the study.

STUDY OBJECTIVES

INTEGRATE SCS CAMERA CONCEPT STUDIES TO:

- DEFINE STS INTERFACE & CONSTRAINTS FOR PALLET EXPERIMENT/OPERATIONS – 1981 AND BEYOND
- DEFINE SCS OPERATIONAL CONCEPTS ATTRACTIVE TO NRP
  - PALLET OPERATIONS
  - FREE-FLYER OPERATIONS
- DEFINE EXPERIMENT/DEVELOPMENT SEQUENCES
  - STEP GROWTH TO ADVANCED TECHNOLOGY FREE-FLYER
  - TECHNOLOGY DEVELOPMENT REQUIREMENTS

MAJOR RESULTS

- SINGLE CAMERA STEREO SHUTTLE PALLET REPRESENTS EXISTING TECHNOLOGY
  - FIRST FLIGHT AS EARLY AS 1982
  - COST/COMMITMENT DETERMINES SCHEDULE
- ETR PALLET PROVIDES 20 DAY MISSION:
  - SIGNIFICANT COVERAGE FOR 45 TO 59 DEG LAT TARGETS
  - 21,000 LB AVAILABLE FOR SHARED PAYLOADS
- WTR PALLET REQUIRES <u>DEDICATED SHUTTLE FLIGHT</u> FOR 15-20 DAY MISSION:
  - PROVIDES COVERAGE ABOVE 57 DEG LAT
  - COVERAGE OF 45 TO 59 DEG LAT TARGETS IS 25 TO 50% OF ETR COVERAGE
- INTERIM WTR FREE-FLYER FOR 1984 AND BEYOND ATTRACTIVE APPROACH
  - SILVER HALIDE FILM WITH SHUTTLE FILM RETRIEVAL
- LOCATION ACCURACIES FOR MC&G OF 25 FT OR LESS CAN BE PROVIDED BY 1986

20 DAY ETR PALLET

The SCS/Shuttle pallet would weigh approximately 5000 lb. The payload support weight to extend the mission from seven to twenty days is 27,400 lb leaving about 21,000 lb for shared payload. The orbit selected for the analysis was 159 nm circular at 57° inclination which yields 15-5/7 revs per day with a seven day repeat/access cycle.

A ±40° camera scan was selected based on a trade-off analysis of a narrow (±16°) sector scan with the capability to point the sensor line of sight ±30°. This results in a nominal increase in the size of the scanning mirror. Mirror size would increase very rapidly for scan angles above ±40°.

The 57° inclination of the orbit provides a significant increase in access (number of opportunities) to targets between 45° and 59°, specifically during the equinox and summer periods. Imagery can be obtained on both ascending and descending passes plus the fact that at these latitudes the access scan distance is signficantly greater than the distance between successive orbit traces from day to day.

The SCS camera designs can obtain NIIRS-4 imagery from 159 nm altitude. However, to meet the performance requirements for low average sun angles resulting from the 57° inclination the camera designs should minimize the smear contribution. The camera smear budget should match the 200 to 225 μrad smear budget contribution from the shuttle. The aperture could be increased to provide a faster system for reduced exposure times.

20 DAY ETR PALLET

PALLET WEIGHT:	• 5000 LB WITH INCREASE CAMERA SCAN TO ±40°
ORBIT:	• 159 NMI CIRCULAR AT 57° INCL (Q = 15 5/7)
QUALITY:	• SCS CAMERA DESIGNS PROVIDE NIIRS-4

OPERATIONAL PALLET REQUIRES MINIMUM OF 3 SHIP SETS

- 2 SYSTEMS IN READY CONDITION FOR EACH LAUNCH (OR ONE READY AND ONE IN SYSTEM TEST FOR CLOSE LAUNCH SPACINGS)
- PERIODIC CAMERA REFURBISHMENT (APPROXIMATELY 12 MONTH DOWN TIME)

18 DAY WTR PALLET

WTR shuttle pallet operations require a *dedicated shuttle launch* into a typical 150 x 218 nm sun synch orbit, i.e., an eccentric orbit is needed for access closure of two access cycles over the 18 day period and the 150 nm perigee is needed for NIIRS-4 imagery.

Coverage of targets above 59° is provided, however, the probabilities of obtaining clear imagery (80% of area) in the dense/bad weather are quite low. The 18 day shuttle pallet would provide slightly more than one third of a 60 day *hexagon* operation due to the higher operating orbit.

The key to these results is that the target access opportunities for WTR pallets to dense areas are significantly less than ETR pallets, resulting from orbit inclination/coverage factors. Consequently, the fewer target accesses result in significantly lower probabilities of success than ETR pallets independent of weather conditions. This fact plus the required *dedicated shuttle launch* make the WTR pallet not attractive.

However, some users are investigating the possibility of transferring from ETR to WTR (after 1984) for 12 hr/63.4° inclination orbits. This would result in the availability of a 63.4° inclination orbit from WTR and would compare in access performance to the projected 57° inclination from ETR. Also, some WTR launches may be at 70°, the lowest inclination without difficult range safety problems. This inclination would provide access performance more similar to that at 57° than that for the syn synchronous case. Consequently, pallets should be classified by performance, as moderate (57° to 70°) inclination vs high (≥80°) inclination orbits rather than ETR or WTR launched.

18 DAY WTR PALLET

- REQUIRES DEDICATED SHUTTLE LAUNCH FOR 150 x 218 NMI SUN – SYNCH ORBIT (97°) (Q = 15 7/9)

– PALLET WEIGHT	5,000 LB
– INCREASED ORBIT LIFE WEIGHTS	
- ELECTRICAL POWER	7,700 LB
- RCS PROPELLANTS (560 LB/DAY)	9,500 LB
- APSIDES CORRECTION PROPELLANTS	2,000 LB
- OMS KITS (DRY)	3,400 LB
– MARGIN (SECONDARY)	800 LB
– INJECTED P/L CAPABILITY	28,500 LB

- QUALITY – SCS CAMERA DESIGNS PROVIDE NIIRS-4
- QUANTITY

INTERIM FREE-FLYER

To consider a more efficient approach, an *interim free-flyer* weighing approximately 8300 lb, incorporating existing technology (silver-halide film with shuttle retrieval) was evaluated for the 1984 time period. The concept would use two or three SVs launched by a single shuttle from WTR into a 170 nm circular sun synch orbit. The SVs would operate at two altitudes: 170 nm for NIIR-4 plus short periods (2 mo) at 130 nm for NIIR-5. Periodic shuttle film retrieval missions (typically 4 mo intervals) with minimum support weight penalties could be used for mission data return.

This system offers the capability for flexible operations, allowing maximum shuttle sharing opportunities. In this concept, system hardware is deployed in orbit where it can be continuously used to collect data. This is in contrast to a pallet operational system which requires a minimum of three "ship-sets" to support an adequate number of periodic short-life operations. With long-life free-flyers, the punishing effects of ascent and reentry environments is also minimized, resulting in less system refurbishment.

A two SV system would provide about 50% more clear imagery return than *hexagon* operating over an equal time period. To implement a reliable system, minimum redundancy in each SV and increased survivability, it may be desirable to add a third SV. The use of a fourth SV in an advanced technology system would provide world-wide daily access with near real-time readout.

The consideration for frequent (typically 2 mo) film retrieval intervals could result in the need for a dedicated shuttle operation. Free-flyer considerations including film retrieval with cassette exchange, on-orbit refueling and service/maintenance will result in increased development costs which could reduce the attractiveness of the interim (silver halide film) free-flyer.

QUANTITY ANALYSIS METHODOLOGY

The key performance issue of this study was the *quantity* of cloud free imagery achievable by shoft life (pallet) operations. While quality requirements, even for low average sun angles, can be satisfied by appropriate sensor design (i.e., aperture and focal length), quantity performance for short life missions could be inherently unsatisfactory.

A statistical approach and methodology was developed to evaluate the quantity of cloud free imagery provided by the various system options. The approach was based on results of previous studies that concluded that *dense target areas* and *near-worst-case weather conditions* provide the limiting quantity performance condition. The probability of at least one look, with 60% cloud free weather (providing, on the average, over 80% cloud free return), at all portions of a 250 nm east-west strip in typical dense target areas was used to measure *quantity* performance.

The dense areas used were Moscow, Europe 50°N-15°E, USSR 51°N-41°E, and south China 25°N-110°E. The Air Force Air Weather Service, located at the STC provided weather statistics based on four years of weather data. The weather patterns were comprised of 5-50 nm cells in the 250 nm strip. On the basis of each cell having better (1) or worse (0) than threshold weather 2^5 or 32 discrete weather patterns for each pass were possible.

Another factor evaluated was the effect on system performance of the limited (±16°) scanning capability of the initial SCS camera designs, which results in an imaging swath less than the 250 nm track width. An access screening matrix was used to compute the pass transition matrix for the cases when the imaging swath was less than 250 nm. The system performance under this condition is highly dependent on spatial correlation of the weather patterns, e.g., the likelihood of the weather being clear over a width greater than the 50 nm cells. For instance, the success probability, $P(\geq 1)$, after the first pass when imaging and access swaths are equal, is the probability that the weather will be clear ($\geq$60% cloud free) over the entire 250 nm swath.

Using stochastic process analysis, pass transition probability matrices were constructed that allowed the computation of the success probability [$P(\geq 1)$] after each successive access. From these data, parametric curves of $P(\geq 1)$ vs access opportunities were generated. For each target area there are three parameters which drive these results (1) probability of 60% cloud free weather for a random grid point (cell), (2) spatial correlation implicit in the weather data, and (3) imaging swath width. To determine the $P(\geq 1)$ success factor for a given mission, the number of access opportunities during the mission was computed based on the orbit, mission duration and the maximum roll obliquity angle for imagery.

The data is used to compute and compare probability of imagery for both poor and moderate weather for short life pallet systems and 60 day free flyers, and compares these to *hexagon* normalized to a 60 day segment of its mission.

INTERIM FREE-FLYER

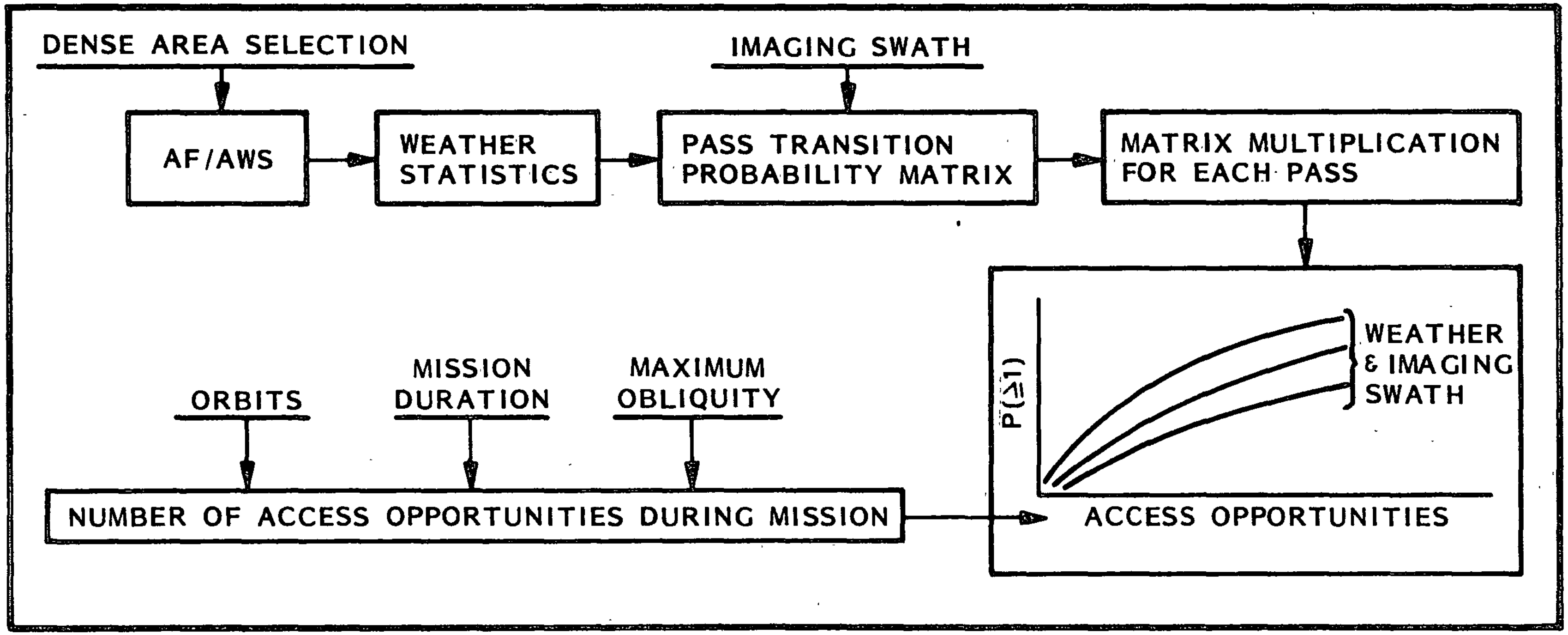
- WTR SHUTTLE
  - CAN LAUNCH UP TO 3 SATELLITE VEHICLES (8300 LB) IN 170 NM CIRCULAR SUN SYNCH ORBIT
  - CAN SUPPORT PERIODIC FILM RETRIEVAL MISSIONS
- TWO SATELLITES IN 170 NM CIRCULAR ORBIT TO MEET NIIRS-4 REQUIREMENTS
  - GOOD REPEAT CYCLE: Q = 15 13/15, 2 SATS → 4 ACCESSES EVERYWHERE EACH 15 DAYS
  - SCS APERTURE SHOULD BE INCREASED ABOUT 13% (170/150) TO MEET NIIRS-4 REQUIREMENTS
  - SCAN SHOULD BE INCREASED FROM ±16° TO ±40° TO PROVIDE ADEQUATE CLOUD-FREE IMAGERY
- DROPPING ONE SATELLITE TO 122 NM TO MEET NIIRS-5 REQUIREMENTS
  - 60-DAY OPERATION (AS NEEDED) IS ADEQUATE DURATION
  - GOOD REPEAT CYCLE: Q = 16 2/11 → 2 ACCESS EACH 11 DAYS
- FLEXIBLE SHUTTLE OPERATION
  - MAXIMIZES SHARING OPPORTUNITIES – PARTICULARLY FOR FILM RETRIEVAL MISSIONS
  - SEVERAL SATELLITE VEHICLES CONTINUOUSLY ON-ORBIT PROVIDES CONTINUITY OF COVERAGE
  - SATELLITE VEHICLES ARE DEPLOYED ON-ORBIT RATHER THAN BEING RECYCLED AND RETESTED ON THE GROUND
- IMPROVED SYSTEM SURVIVABILITY
- GOOD GROWTH POTENTIAL FOR TECHNOLOGY IMPROVEMENTS

QUANTITY ANALYSIS METHODOLOGY

EVALUATION CRITERIA

CONCLUSION: A MEANINGFUL MEASURE OF QUANTITY PERFORMANCE IS: P(≥1) = PROBABILITY OF AT LEAST ONE LOOK, WITH 60% CLOUD FREE WEATHER, AT ALL PORTIONS OF A 250 NM EAST-WEST STRIP IN TYPICAL DENSE TARGET AREAS.

REFINED ANALYSIS - COMPUTATION OF P(≥1)



PERFORMANCE SUMMARY

The evaluation of the SCS performance (quantity of cloud free imagery returned), used both seasonal weather and associated access opportunity data for several *dense area* locations. Shown in the performance summary are south China and Europe. The table summarizes the results for: (1) 20 day ETR pallet; (2) 18 day WTR pallet and (3) WTR free-flyer operations with two satellites operating at 170 nm (NIIRS-4) and one satellite at 130 nm (NIIRS-5). In addition, the same model was used to evaluate *hexagon* (over a 60 day period) and performance of the four systems were compared.

A significant factor in this analysis was that the weather used for computing the thresholds (PROBLOOK) was typical for a 3-month period and the number of target access opportunities correspond to the specific 3-month period.

The analysis shows that ETR pallets approached 100% success at the 50° latitude European targets for spring, summer and fall and about 75% success for winter. The performance at 25° latitude (China targets) varied significantly with season. In winter, during good weather ETR pallets had about a 0.75 success probability. However, during the other seasons the success probability varied between 0.3 and 0.4.

WTR pallets have a significantly lower performance capability than ETR pallets. The WTR interim free-flyer system evaluated for 60 days of operation every three months has high probability of success. The three satellite configuration would allow growth capability above the current stated mid-1980 search requirements.

PERFORMANCE SUMMARY

QUANTITY PERFORMANCE IN REPRESENTATIVE WEATHER BY SEASON DENSE TARGET AREAS AT 25° CHINA AND 50° EUROPE LATITUDE

	P(≥1)								AVERAGE VALUE OF P(≥1) ÷ HEXAGON P(≥1) FOR 25° AND 50° LAT			
	WINTER D, J, F		SPRING M, A, M		SUMMER J, J, A		FALL S, O, N					
LATITUDE	25°	50°	25°	50°	25°	50°	25°	50°	WINTER	SPRING	SUMMER	FALL
PROBLOOK	0.287	0.155	0.104	0.226	0.101	0.239	0.155	0.239				
SPATIAL CORRELATION	STRONG	MEDIUM WEAK	STRONG	MEDIUM WEAK	WEAK	MEDIUM STRONG	MEDIUM WEAK	MEDIUM STRONG				
ETR PALLET ±40° ACCESS, 20 DAYS	0.74	0.74	0.39	0.98	0.29	0.99	0.41	0.99	1.08	0.94	0.96	0.92
WTR PALLET ±40° ACCESS, 18 DAYS	0.58	0.32	0.24	0.53	0.13	0.58	0.23	0.58	0.61	0.54	0.51	0.53
FREE-FLYERS (WTR) ±40° ACCESS, 60 DAYS												
170 NM, 2 SATS	0.99	0.99	0.91	0.99	0.84	0.99	0.97	0.99	1.45	1.47	1.77	1.44
130 NM, 1 SAT	0.93	0.78	0.57	0.94	0.56	0.96	0.62	0.96	1.23	1.10	1.35	1.10
HEXAGON (REF) ±45° ACCESS, 60 DAYS	0.90	0.55	0.50	0.89	0.34	0.92	0.54	0.92				

CONCLUSIONS

(1) ETR pallets are an attractive approach combining both operational and experimental capabilities. Three to four operations per year will provide a significant contribution to meeting the overall wide area search requirements. The limitation of the ETR pallets are the frequency of film return (due to the limited number of shuttle flights per year) and the inability to cover targets above 59° latitude.

(2) WTR sun synch pallets are not an attractive approach from both performance and cost points of view.

(3) WTR free-flyer evolutionary concepts could meet the intelligence requirements for 1984 and beyond, initially with film retrieval with growth potential to incorporate advanced technologies for near real-time data return. However, preliminary investigation of the interim free-flyer indicate a number of significant facts which could lead to increased costs. These include questionable availability of shared shuttle operations for film retrieval, film cassette exchange techniques, refueling and on-orbit service/maintenance.

It shall be noted that these cost factors would have minimum impact on the advanced technology near real-time readout free-flyer.

CONCLUSIONS

- ETR PALLETS COMBINE:
  - (1) OPERATIONAL CAPABILITY FOR DENSE AREAS
  - (2) EXPERIMENTAL CAPABILITY – OPPORTUNITIES
- WTR PALLETS ARE NOT ATTRACTIVE
  - (1) DEDICATED SHUTTLE FLIGHT
  - (2) LIMITED COVERAGE/ACCESS OF DENSE AREAS
- WTR FREE-FLYER EVOLUTIONARY CONCEPTS CAN MEET INTEL REQUIREMENTS FOR 1984 AND BEYOND
  - (1) INTERM – WITH FILM RETURN
  - (2) ADVANCED – WITH NEAR REAL TIME DATA RETURN

RECOMMENDATIONS

The choice between pallets and free-flyers is dependent on the stated *decision drivers*. The 2-month data return interval requirement drives the availability of shared shuttle flights and could result in dedicated shuttle operations for both pallets and free-flyers. However, deleting the 2-month SCS system requirement may result in adequate (3 to 4) shared shuttle opportunities per year. It is anticipated that the interim free-flyer would incur higher development and lower operational costs than the pallet. The span between initiation of full operations of pallets or interim free-flyers (~1984) and advanced free-flyers (1986-1988) allows minimal time for amortization of the fairly extensive dead-end development costs for a film cassette free-flyer system.

The availability of the 1984 national resources would allow the 2-month data return interval requirement to be deleted. The high latitude targets can probably be satisfied by current national resource. These conclusions are based on a previous *shuttle/mix* study performed by BIF003/2 for SP-6 during 1976-77.

Consequently, it is recommended that SAFSP pursue the development of a SCS pallet system on the basis of 3 to 4 flights per year which, when coupled with other national resources, can meet the wide area search requirements in the most cost-effective manner in the 1984-1988 time period. In addition, the SCS pallet can function as a technology development laboratory for the advanced free-flyer. The potential capability in terms of both performance (including near real-time readout of wide contiguous areas) and improved survivability leads to the recommendation to continue advanced free-flyer supporting technology developments, including photo condutive film, electronic readout and laser communication links. In summary, the recommended approach would evolve from the silver-halide film pallet to the advanced technology free-flyer.

RECOMMENDATIONS

DECISION DRIVERS (PALLET VS INTERIM FREE-FLYERS)

- AVAILABILITY OF SHARED SHUTTLE FLIGHTS
- PROJECTED OPERATIONAL DATE FOR ADVANCED TECHNOLOGY FREE-FLYER (1986-1988)
- AVAILABILITY OF "PLANNED" NATIONAL RESOURCES (1984?)

RECOMMENDATIONS

- DELETE INTERIM SCS REQUIREMENTS FOR:
  - 2 MONTH RETURN INTERVAL
  - HIGH LATITUDE TARGET COVERAGE
- PURSUE PALLET DEVELOPMENT/OPERATIONS
  - 57° INCLINATION – ETR
  - 63.4° TO 70° INCLINATION (WTR) ALTERNATIVE
- CONTINUE TECHNOLOGY DEVELOPMENTS FOR ADVANCED FREE-FLYER

2 SCS CAMERA CONCEPTS

SINGLE CAMERA STEREO CONCEPTS - BACKGROUND

The results of the single camera stereo (SCS) camera concept studies performed by EK, Fairchild, ITEK and P-E provided the starting point for this study. We reviewed their final reports and then met with each payload contractor. The results were reviewed with SP-6 and the decision was made to use only the EK and Fairchild design concepts for the SCS/Shuttle study. The two approaches were considered to be representative concepts for a SCS system.

SINGLE CAMERA STEREO P/L REQUIREMENTS

The requirements specified to the four payload contractors by SP-6 addressed the advanced technology free-flyer. The operational concept would include up to 4 free-flyers continuously in orbit and the system would provide daily world-wide access. Near real-time readout would be accomplished by using photo-conductive (PC) material in the sensor focal plane. The payload contractors used 1414 film characteristics for performance calculations to provide compatibility for growth to the PC material, since Coulter Labs is using the characteristics of 1414 for the development goals for the PC material.

SINGLE CAMERA STEREO P/L REQUIREMENTS

ALTITUDE RANGE:	150 TO 180 N. Mi
GROUND RESOLVED DISTANCE:	0.8 METERS (31.5 IN.) NADIR
IMAGING SWATH:	160 KM CROSS-TRACK (CONTINUOUS IN-TRACK)
STEREO CONVERGENCE:	20° TO 55°
VEHICLE SMEAR CONTRIBUTION:	400 μRADS/SEC
PERFORMANCE ESTIMATES:	BASED ON 1414 FILM

CAMERA NO. 1 CONCEPT

The Camera No. 1 (EK) concept utilizes the Maksutov optical design form which, in its purest form, has a full aperture meniscus corrector whose radii are concentric with the center of curvature of a spherical primary. The stop of the system is nominally at the corrector and therefore the system requires a primary larger than the corrector to accommodate off axis imagery without vignetting. The field curvature due to the curvature of the primary must be compensated by addition of a refractive field group near the focal plane. Optical design programs now permit optimization of design form, including the use of aspheric surfaces, so that off-axis performance is nearly equal to on-axis performance.

Reflective systems have the problem of extracting the image from the system after the optical axis is folded back on itself. In this design the trapazoidal folding flat makes the image accessible. The flat results in a central obstruction of the aperture (an unavoidable condition) which depresses the middle spatial frequencies of the Modulation Transfer Function (MTF). The middle spatial frequencies become important for low contrast targets at low sun angles and/or high obliquities. Not only do central obstructions result in loss of resolution (compared to unobstructed systems) for low contrast targets, but also they reduce subjective quality factors and hence NIIRS ratings for the same limiting resolution. Therefore, the obscuration (folding flat) has been deliberately minimized by:

a. Keeping the aperture ratio (F/No) reasonable (e.g., F/4 rather than F/3).

b. Keeping the focal plane as close as possible to the lens barrel.

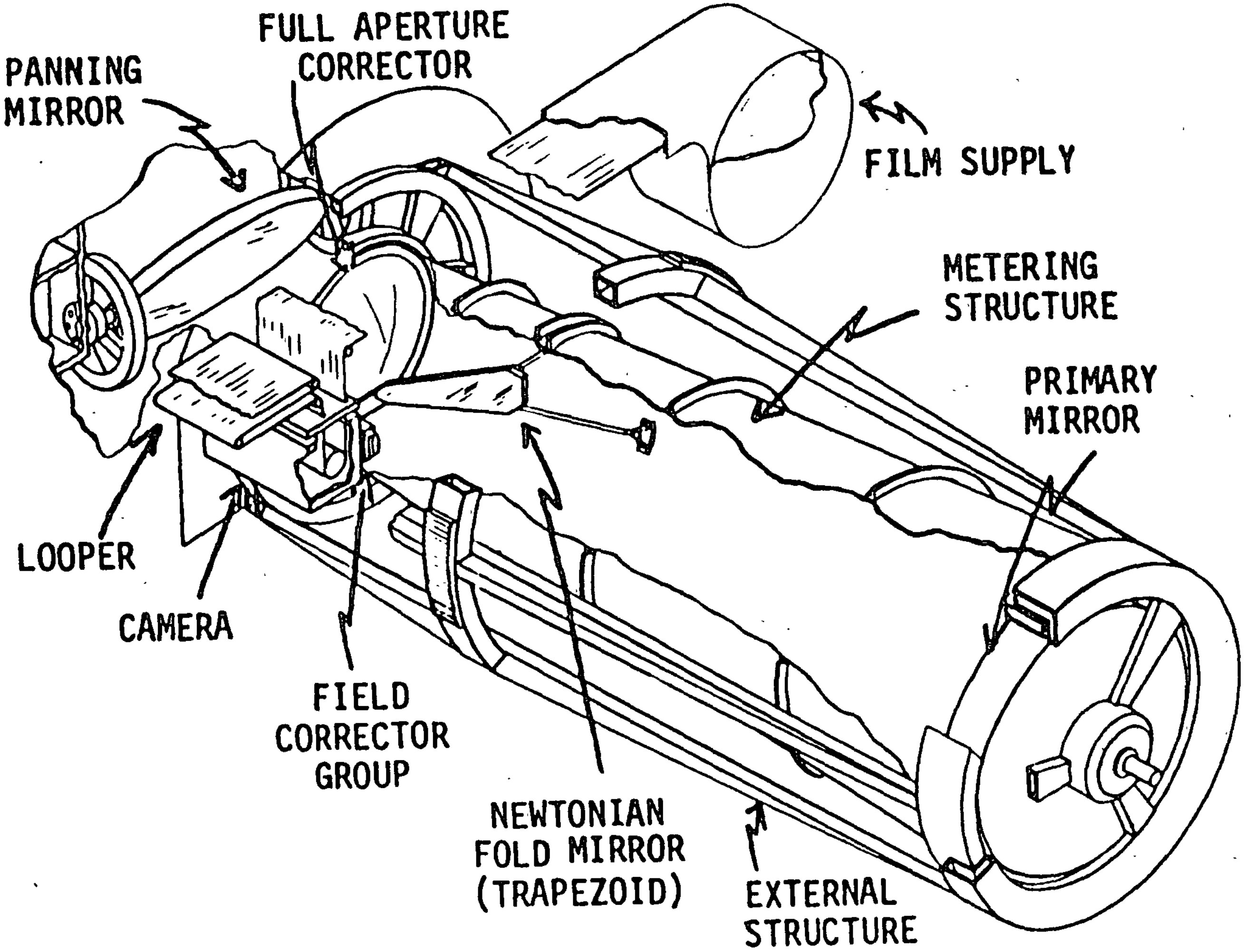
c. Operating at the lowest possible film drive speeds so that the minimum slit widths and, hence, field corrector widths may be achieved.

The Maksutov design, when optimized, will perform better at wider field angles than many alternate design forms so that up to the point where off-axis residual geometric smear begins to limit off-axis resolution, the wide angle attributes of the Maksutov allow wider film and lower film speeds which permit a small obstruction and a cylindrical platten. A low speed phase locked cylindrical platten has superior jitter characteristics when compared to alternative concepts. These considerations are an excellent example of the subtle interactions of compelx factors in system synthesis.

Cross track panoramic imagery is acquired with this camera concept by orienting the optical axis athwartship on the host vehicle and scanning is accomplished with an oscillating elliptical flat. Forward motion compensation (FMC) is accomplished by a slight rotation of the lens barrel (and scanning mirror) about the barrel axis during the scan.

There are three growth limiting factors for this concept. First, given the desirability of a scan capability of ±40°, the scanning flat must be separated from the optical tube by a distance such that at one extreme scan angle (say +40°) the mirror does not hit the optical barrel, and at the other extreme scan angle (say -40°) the optical barrel does not obstruct the line-of-sight. If a growth version of this concept were used as an STS pallet payload, the athwarship length could grow to exceed the Shuttle bay dimensions. Second, there is an upper limit on the largest refractive corrector which is obtainable. Current estimates suggest 24-30 in. as the upper limit. Third, as the camera No.1 concept is scaled up, the dimensions, and especially the mass, of the scanning flat, increase dramatically. The mirror mounting and servo system which can accelerate an oscillating mirror smoothly without ringing have yet to be demonstrated. The scanning mirror and servo are the technical challenge of this concept.

CAMERA #1 CONCEPT



CAMERA NO. 2 CONCEPT

The camera No. 2 (Fairchild) concept utilizes the Petzval optical design form which is an all refractive system having, in its original form, two widely separated lens groups, each with positive power. Although the physical length of a Petzval exceeds the focal length by about 50%, the distribution of optical power between the groups and the large separation between the groups permits a practical folding scheme which results in a very compact package. Two folds, the first between the two positive groups, the second after, result in a configuration called an optical bar. An optical bar is a system which is spun about the part of its optical axis between the two flats.

The Petzval design form is capable of high speed (e.g., F/2.8) and large fields of view (up to 12°). Long focal length designs typically incorporate two air spaced doublets or triplets and an additional negative field flattening group with two or more elements. The second fold of the optical bar may be before or after the field flattening group. In this concept (No. 2) the second fold is placed after the field flatteners. Computer assisted designs utilizing current glass catalogs closely approach diffraction limited performance.

Cross track panoramic scanning is accomplished by orienting the axis of the optical bar vertically so that the front lens group (before the first fold) scans in a horizontal plane. Two pointing flaps mounted athwartship one forward, the other aft of the optical bar, provide scanning access. The length (athwartship) of the flats determines the limits (e.g., ±40°) of the scan. The flats are oriented 45 + stereo convergence angle and 45 - stereo convergence angle respectively with respect to the vertical.

Forward motion compensation is accomplished by a slight rotation of the pointing flats about their athwartship axes during the scan.

There are two growth limiting factors for this concept. First, as the aperture of the system grows (diameter of the first group) the separation between the bar and the flats must increase so that the bar will not graze the flats. Increase in separation causes a dramtic increase in length to accommodate a ±40° scan. The technology to polish large flats has been demonstrated, but the cost and weight may become excessive. Second, there is an upper limit on the size of all refractive optics due to the availability of glass. Whereas, a Schmidt corrector plate could conceivably be made from "float" glass in very large apertures (40-80 in.) and a Maksutov corrector of BK-7 (a very common type) might be had in sizes exceeding 30 in.; a Petzval system is probably limited to about 24 in. The "glass houses" are not prepared to supply some of the more exotic glasses required for adequate color correction in sizes larger than 24 in.

The transparent film support cylinder and its servo as well as the optical bar servo are the technical challenge of this concept. Not only must the support cylinder maintain stable concentric operation within a few tenths of a milliradian to maintain focus but also, the drum velocity must be accurately synchronized to the image velocity. For camera systems operating in the 100 in./sec regime, film velocity synchronization has been the major factor limiting performance.

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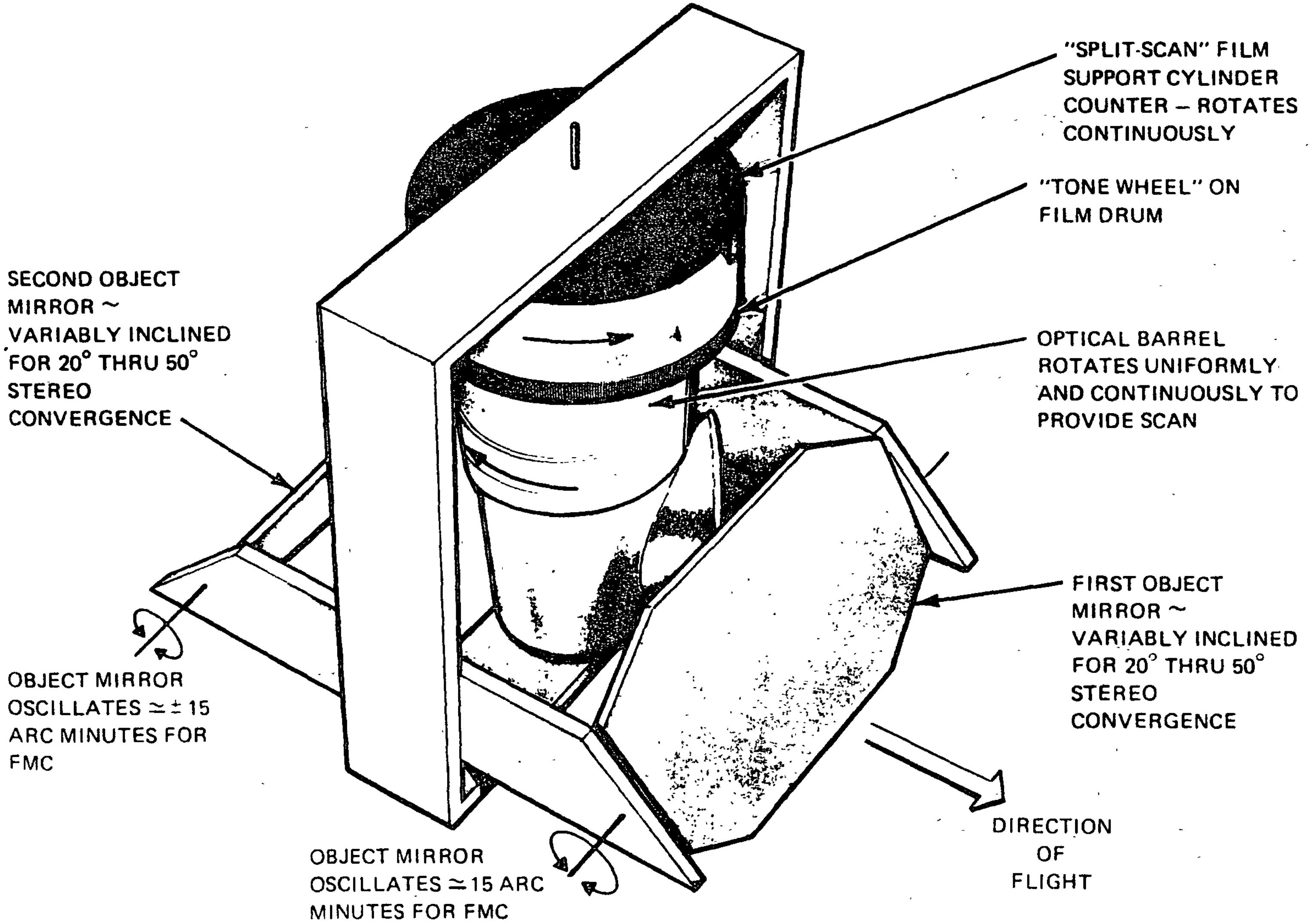
CAMERA #2 CONCEPT



CAMERA CHARACTERISTICS

A comparison of the EK (Camera No. 1) and Fairchild (Camera No. 2) designs show that the apertures and focal lengths are similar with the unobstructed (Fairchild) design being slightly smaller as expected. The two systems use radically different scanning techniques. The EK system has a design challenge in the scanning mirror and the Fairchild system has a design challenge in the transparent recording drum from which the film must be lifted during part of the cycle. Traditional forward motion compensation for both systems introduces residual image rotation which cannot be removed without another degree of freedom which neither system (as proposed) possesses.

The EK system utilizes a 50% wider format than the Fairchild system. The wider format permits lower film drive speeds but both systems (and all tilted cameras) have an off axis geometric smear called change of magnification. This smear is due to the fact that a tilted camera does not have its focal plane parallel to the object plane. Since the smear scales linearly with field position and with the sine of the pitch (tilt) angle, there is a limit both to useful field width and to the stereo convergence angle. Increasing stereo convergence increases off axis smear so that a point is reached for which stereo accuity does not increase. This subject deserves further study. Schemes to reduce or eliminate image rotation and change of magnification should be investigated further.

CAMERA CHARACTERISTICS

		CAMERA NO. 1	CAMERA NO. 2
OPTICS	TYPE OF OPTICS	CATADIOPTIC	TRANSMISSIVE
	FOCAL LENGTH	72 IN.	66 IN.
	APERTURE	18 IN.	17.4 IN.
	F NUMBER	4.0	3.8
	OBSTRUCTION RATIO	~ 12 PERCENT	ZERO
POINTING	SCAN TECHNIQUE (32° CROSS-TRACK)	NODDING FLAT (OP AXIS⊥ORBIT PLANE)	ROTATING OPTICS (VERTICAL OPTICAL BAR)
	FORE/AFT VIEW SWITCHING	ROTATE CAM W.R.T. VEH	ALT USE OF 2 PT'G FLATS
	FORWARD MOTION COMPENSATION	ROTATE OPTICS	ROTATE POINTING FLAT
FILM HANDLING	FILM WIDTH	9 IN.	6 IN.
	FOCAL PLANE FILM HANDLING	BACK-SIDE ROLLER	FRONT-SIDE DRUM
	FILM TWIST IN CAMERA	NONE	NONE
	APPROXIMATE FILM SPEED	36 IN./SEC	97 IN./SEC

3 SCS SYSTEM CONCEPTS

SINGLE CAMERA STEREO SYSTEM DESIGN CONCEPTS

Two different kinds of systems have been investigated for implementation of the SCS system. They both use the shuttle for orbit injection and operation. One system uses the pallet concept in which the SCS system is mounted on a pallet which stays with the shuttle for its total mission. The other system uses a free flyer which is injected into orbit by the shuttle (as many as four free flyers could be injected in a single launch).

Two pallet implementations were studied. One was configured around the EK camera and the other around the Fairchild camera. Typical mounting installations are shown for both. Important pallet-shuttle interfaces were identified and compatibility was established.

Using the different camera designs four free-flyer configurations were formulated, one for each camera in each of two categories. The two categories were interim and advanced camera technology (i.e., silver halide and photo-conductive film).

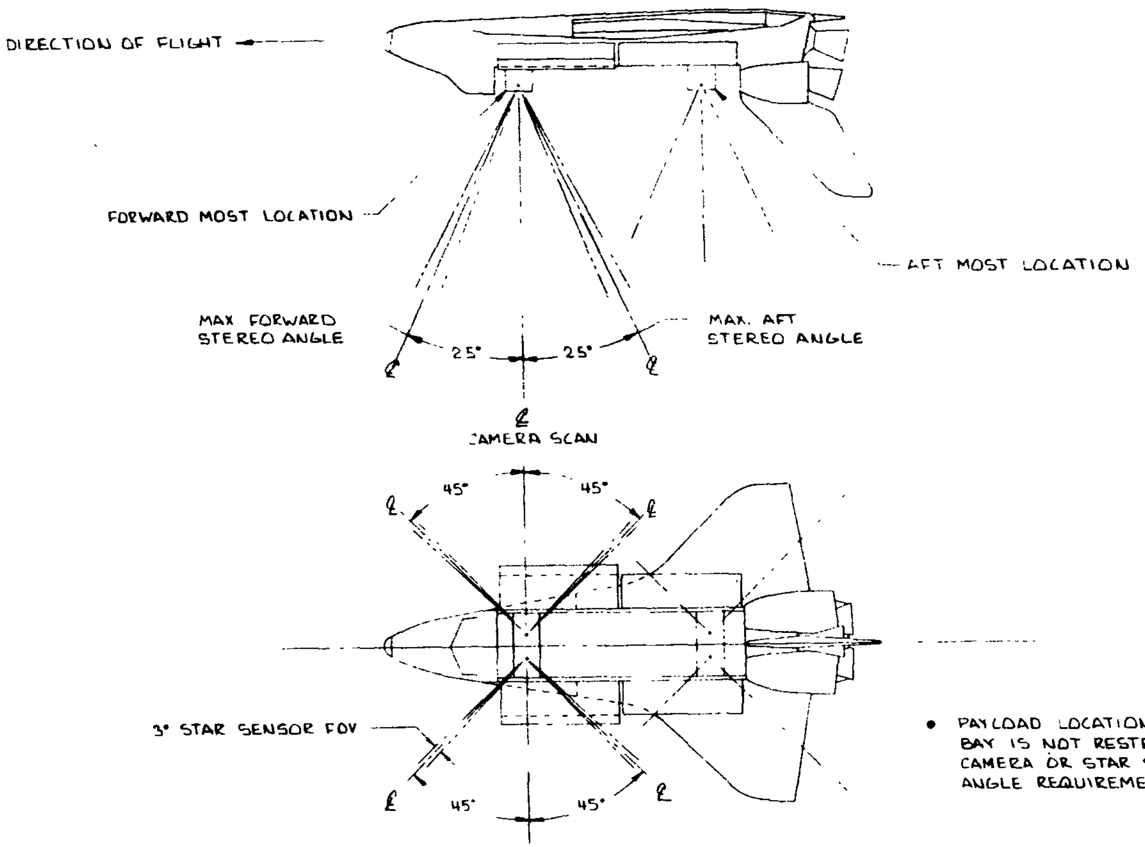
A preliminary weight analysis shows that the pallet installation should weigh about 5000 lb and that the free flyers (interim and advanced) should weigh about 8300 and 9300 lb respectively.

SCS LOCATIONS

The study investigated both pallet and free-flyer SCS concepts. In considering pallet concepts the basic factors are: (1) the primary sensor (SCS cameras) must be earth pointing; (2) the shuttle must be in an upside down (tail down) orientation; and (3) star sensors must look at least 5° above the horizon during imaging. An additional factor is that the SCS camera designs provided ±16° scanning. For short life pallet operations the system requires target access to at least ±40° in roll (from nadir). Consequently, there are three options available to provide the required access: (1) roll the shuttle vehicle, (2) provide a roll gimbaled mount for the SCS camera and (3) increase the scan of the SCS camera to ±40°.

Data received from RI indicated that rolling the shuttle was not a practical approach for this mission due to large propellant usage and long settling time. Trade-off analysis showed greatest gain for (3), increasing the SCS scan to ±40°, particularly in terms of increase in quantity of take.

SCS LOCATIONS



- PAYLOAD LOCATION IN CARGO BAY IS NOT RESTRICTED BY CAMERA OR STAR SENSOR VIEW ANGLE REQUIREMENTS

PALLET INTERFACES

The major pallet-shuttle interface relates to the requirement for precise attitude reference for the camera. Two types of attitude related constraints are of concern. They are for basic alignment and control on the one hand and knowledge on the other. Typically, the requirement for knowledge is much more severe than that for control. The most severe knowledge requirement stems from the MC&G requirement for imagery location to the order of 25 ft. This requires knowledge of a camera LOS pointing to about 3 arc sec. It is for this requirement that the star sensors are needed.

Typically attitude alignment and control will be achieved by a combination of installation alignment with knowledge of that alignment plus on-orbit calibration of critical alignments. Typically, this will be accomplished, probably periodically, by pointing the camera at the stars.

With nominal alignment and control and good knowledge, high performance can be achieved by appropriate modeling. If physical misalignments are maintained within 1° (needed for proper targeting), allowable smear rates at the image plane can be obtained with camera servo control using (in-flight) directional knowledge of the specified accuracy.

Preliminary analysis based on data received from RI indicates that for orientation and control the shuttle attitude system will be adequate if appropriate on-orbit calibration of that system is performed. Reduction of quoted attitude uncertainties from the order of 2° to the order of ½° should be achievable with accurate knowledge available from the precision attitude determination system. More STS information is required in this area; whether shuttle attitude performance is adequate for all missions other than MC&G depends on this result.

To guarantee the integrity of star-to-camera calibration with time, the star sensors should be mounted as close to the camera as possible. This means that the sensors should be on the pallet. This may pose some mounting-view angle problems; but they appear amenable to reasonable solution.

PALLET INTERFACES

ATTITUDE REFERENCE

REQUIRED ACCURACIES(1σ):

(1) MECHANICAL: <1° ALL AXES, 0.01°/SEC RATE

(2) IN-FLIGHT KNOWLEDGE: 0.25° YAW, 0.5° PITCH AND ROLL

(3) POST-FLIGHT (MC&G): ~3 ARC SEC

PRIMARY APPROACH

ORBITER REFERENCE FOR (1) AND (2)

- MODEL ALL ERRORS SOURCES – USE CALIBRATED CORRECTIONS
- USE ATTITUDE DATA WORD FROM ORBITER IF NEEDED
- DRIVE CAMERA FILM VELOCITY (SPEED AND ANGLE) SERVOS AS NEEDED TO CORRECT FOR COMPUTED ERRORS
- STATUS: PRELIMINARY ANALYSIS, BASED ON INITIAL ROCKWELL THERMAL DEFLECTION DATA INDICATES FEASIBILITY. ADDITIONAL ORBITER DATA NEED HAS BEEN IDENTIFIED

PALLET MOUNTED STAR SENSORS FOR (3)

ALTERNATE APPROACHES

IMC INCORPORATED IN CAMERA

USE PALLET MOUNTED IN-FLIGHT ATTITUDE REFERENCE

- TO COMMAND ORBITER ATTITUDE, OR
- TO DRIVE CAMERA SERVOS FOR COMPENSATION OF ORBITER ERRORS

PALLET INTERFACES (CONTINUED)

The tracking, telemetry, and command functions impose no significant or special problems on system implementation.

GPS tracking will be necessary to meet MC&G requirements for real time ephemeris accuracy. The preferred mode of handling GPS data will be to record the position of the satellite as established in real time by GPS directly on the primary record, and preliminary analysis indicates that this is feasible.

Thermal – A primary thermal consideration is the temperature rise in the equipment bay subsequent to landing which requires that "air conditioned" air be supplied to the bay within 15 min of landing.

Contamination – The SCS pallet will require an enclosure for security which can be used to reduce contamination. Operational procedures can minimize contaiminants during periods of camera operations.

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PALLET INTERFACES (CONT)

TRACKING, TELEMETRY AND COMMAND

PRIMARY:	PALLET: RECORDER, ENCRYPTOR/DECRYPTOR ORBITER: SGLS (SPACE-GROUND LINK SYSTEM) COMPATIBLE TRANSPONDER
ALTERNATIVES:	(1) USE ORBITER RECORDER ● IMPLIES GROUND DELAY FOR RECORDING/REVERSING/DECRYPTING CYCLE (2) PALLET MOUNTED TRANSPONDER FOR SGLS COMPATIBILITY ● SCHEDULE DEPENDENT – REMOTE STATION MODS NEEDED FOR ORBITER/SGLS COMPATABILITY

GPS POSITION DATA (MC&G)

PRIMARY:	SEND DATA TO PALLET FOR DIRECT RECORDING ON FILM (STATE VECTOR FROM ORBITER AT 2 SEC INTERVALS)
SECONDARY:	ORBITER RECORDS DATA ON COMMON TIME BASE

THERMAL:	ENCLOSED PALLET AND POST-FLIGHT COOLING AIR
CONTAMINATION	● ENCLOSED PALLET WITH DOORS CLOSED BETWEEN OPS ● FILTER AIR INTO HOUSING DURING REENTRY
ACOUSTIC:	ENVIRONMENT AT LAUNCH STILL SOMEWHAT IN DOUBT ● NEW DATA EXPECTED THIS SUMMER

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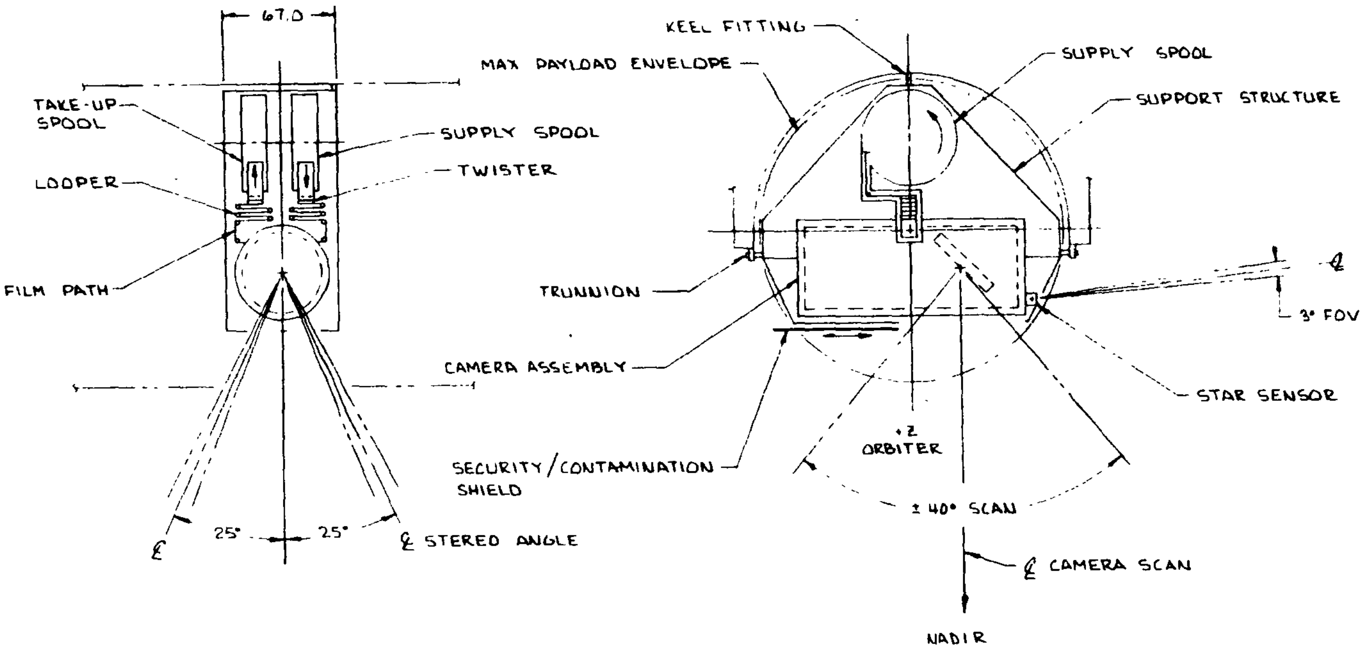
CAMERAS NOS 1 & 2 ±40° SCAN

The alternative of increasing the camera scan to ±40° was selected for the pallet P/L design. Improvement in system quantity performance resulting from the increased scan dictated this selection. The impact on the SCS camera designs was coordinated with both EK and Fairchild and resulted in a modest increase in the size of the panning (EK) and pointing (Fairchild) mirrors. The ±40° maximum scan was selected since size of the mirrors increases very rapidly for scan angles above ±40°. Other advantages of the increased camera scan are described in the appendix. For example, by scanning with the camera rather than the vehicle the problem of providing clear look angles for the star sensors is minimized.

The Fairchild concept is a symmetrical configuration with a vertical (refractive) rotating optical bar. It combines forward and aft pointing mirrors and scanning is accomplished by the rotating bar. Separate film paths and focal planes are provided for both the forward and aft pointing mirrors.

The EK concept is reflective and uses a single pointing/scanning mirror to get the ±40° scan and rotates the camera forward and aft for stereo. Consequently, a single film path focal plane is used.

CAMERA #1 – ±40° SCAN



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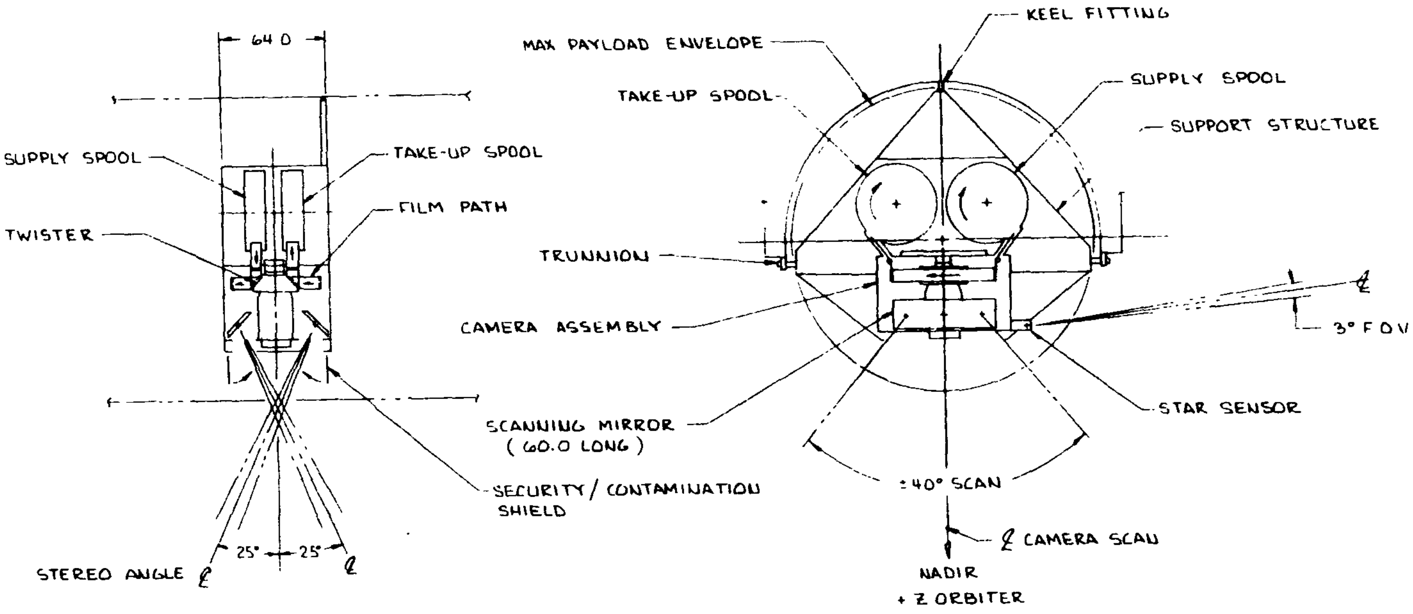
CAMERA #2 — ±40° SCAN



FREE-FLYERS

Preliminary designs for both an interim and advanced technology free-flyers are presented for both camera designs. The interim free-flyer uses silver-halide film with shuttle retrieval of the film. The advanced technology free-flyer incorporates photo-conductive (P-C) film with electronic charge readout via a laser communication link through a relay satellite. The weight and size of the *advanced technology* elements of the system are preliminary estimates based on technology projections.

Additional *interim free-flyer* considerations are described in the appendix which includes factors such as: (1) easy access film cassettes, (2) shuttle maintenance, (3) propellant refueling and, (4) updated weight estimates.

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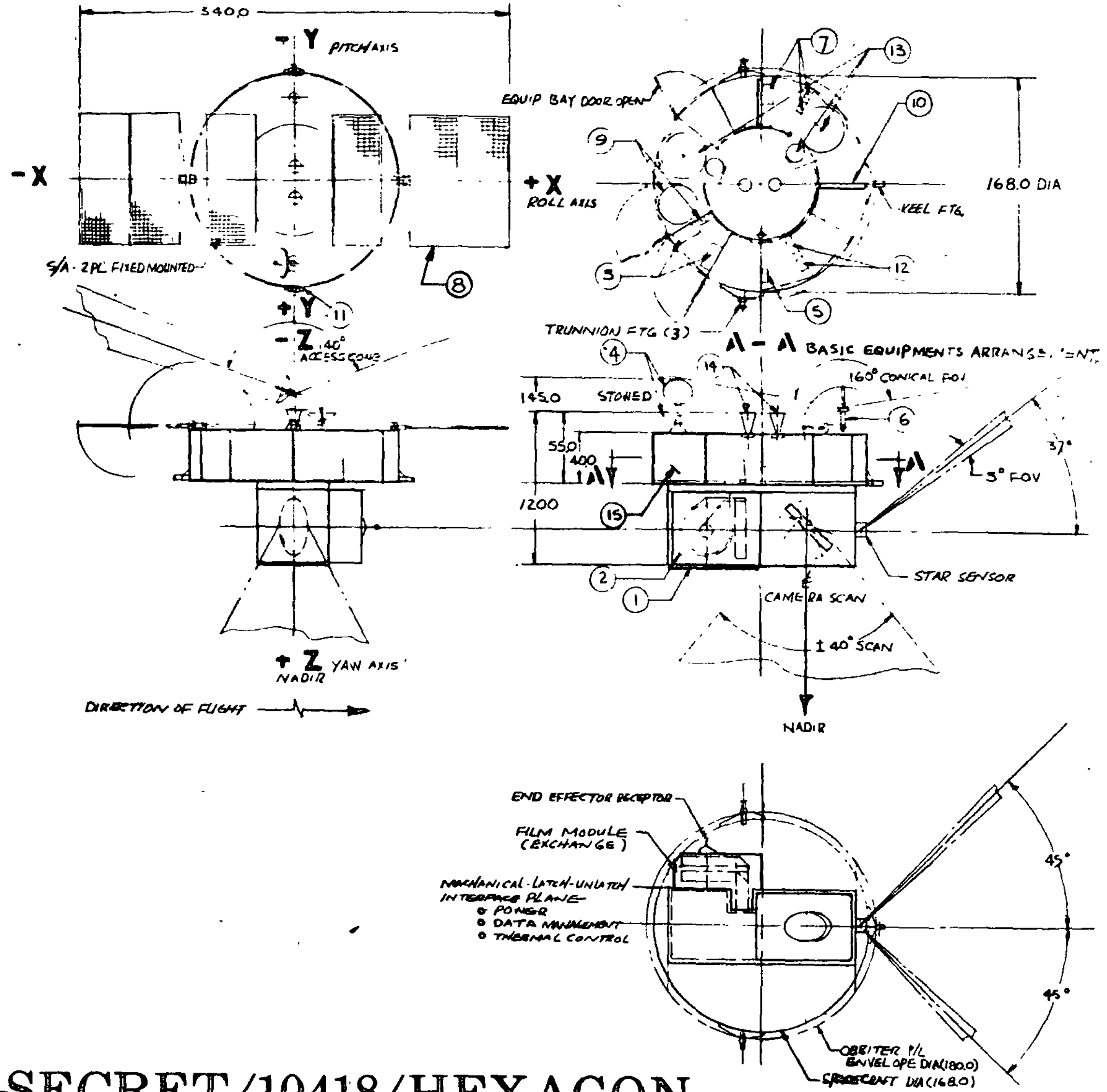
INTERM FREE FLYER CAMERA 1

SUBSYSTEM COMPONENTS

ITEMS	COMPONENTS
①	CAMERA ASSY
②	FILM MODULE ASSY
③	SPACE COMMUNICATION LINK • RECEIVER • TRANSMITTER
④	SPACE COMM LINK ANTENNA (2 AXIS GIMBAL)
⑤	GPS • RECEIVER • COMPUTER
⑥	GPS ANTENNA (DEPLOYABLE)
⑦	ELECTRICAL POWER • BATTERY • CHARGE CONTROLLER • DISTRIBUTION & CONTROL • REGULATOR • I/F CONTROL ELECTRONIC
⑧	SOLAR ARRAY ASSY (2 AXIS TRACKING WING)
⑨	ATTITUDE CONTROL • MOMENTUM WHEELS • CONTROL ELECTRONIC • COMPUTER
⑩	MAGNETIC TORQUERS
⑪	RCS / THRUSTERS/PLUMBLING
⑫	TELEMETRY & COMMAND • RECORDER • TEL. TRACKING & COMM BOX
⑬	PROPULSION • TANK ASSY, H_e TANK & PLUMBING • FUEL (MMH) OXIDIZER (N_2O_4)
⑭	ENGINE SYSTEM • BIPROPELLANT • 100 LBS THRUST
⑮	STRUCTURE/MECHANICAL ASSY ELECTRICAL HARNESS & CONNECTOR



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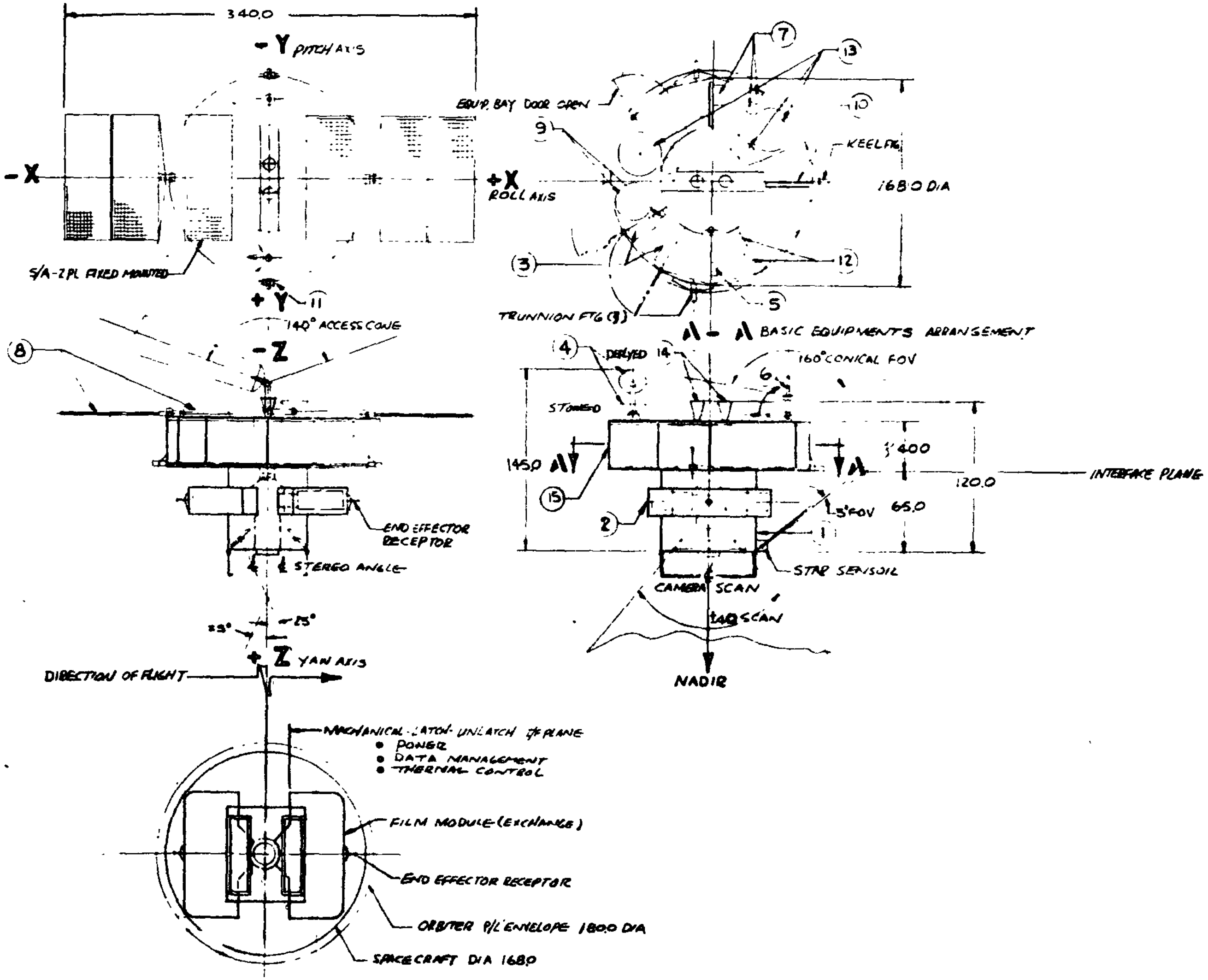
INTERM FREE FLYER CAMERA 2

SUBSYSTEM COMPONENTS

ITEMS	COMPONENTS
①	CAMERA ASSY
②	FILM MODULE ASSY
③	SPACE COMMUNICATION LINK • RECEIVER • TRANSMITTER
④	SPACE COMM LINK ANTENNA (2 AXIS GIMBAL)
⑤	GPS • RECEIVER • COMPUTER
⑥	GPS ANTENNA (DEPLOYABLE)
⑦	ELECTRICAL POWER • BATTERY • CHARGE CONTROLLER • DISTRIBUTION & CONTROL • REGULATOR • I/F CONTROL ELECTRONIC
⑧	SOLAR ARRAY ASSY (2 AXIS TRACKING WING)
⑨	ATTITUDE CONTROL • MOMENTUM WHEELS • CONTROL ELECTRONIC • COMPUTER
⑩	MAGNETIC TORQUERS
⑪	RCS / THRUSTERS/PLUMBING
⑫	TELEMETRY & COMMAND • RECORDER • TEL. TRACKING & COMM BOX
⑬	PROPULSION • TANK ASSY, He TANK & PLUMBING • FUEL (MMH) OXIDIZER (N2O4)
⑭	ENGINE SYSTEM • BIPROPELLANT • 100LBS THRUST
⑮	STRUCTURE/MECHANICAL ASSY ELECTRICAL HARNESS & CONNECTOR



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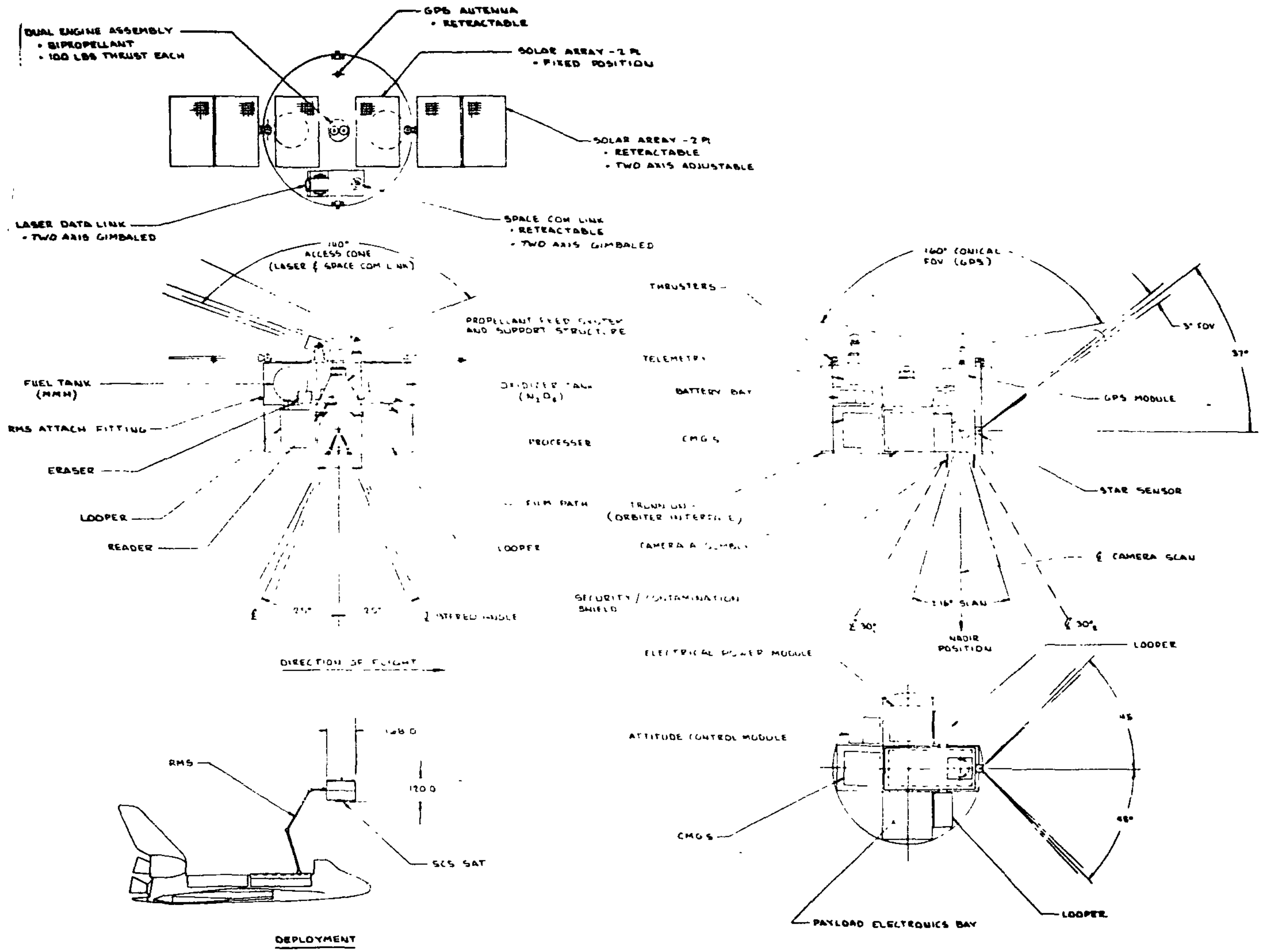
ADVANCED FREE FLYER, CAMERA 1



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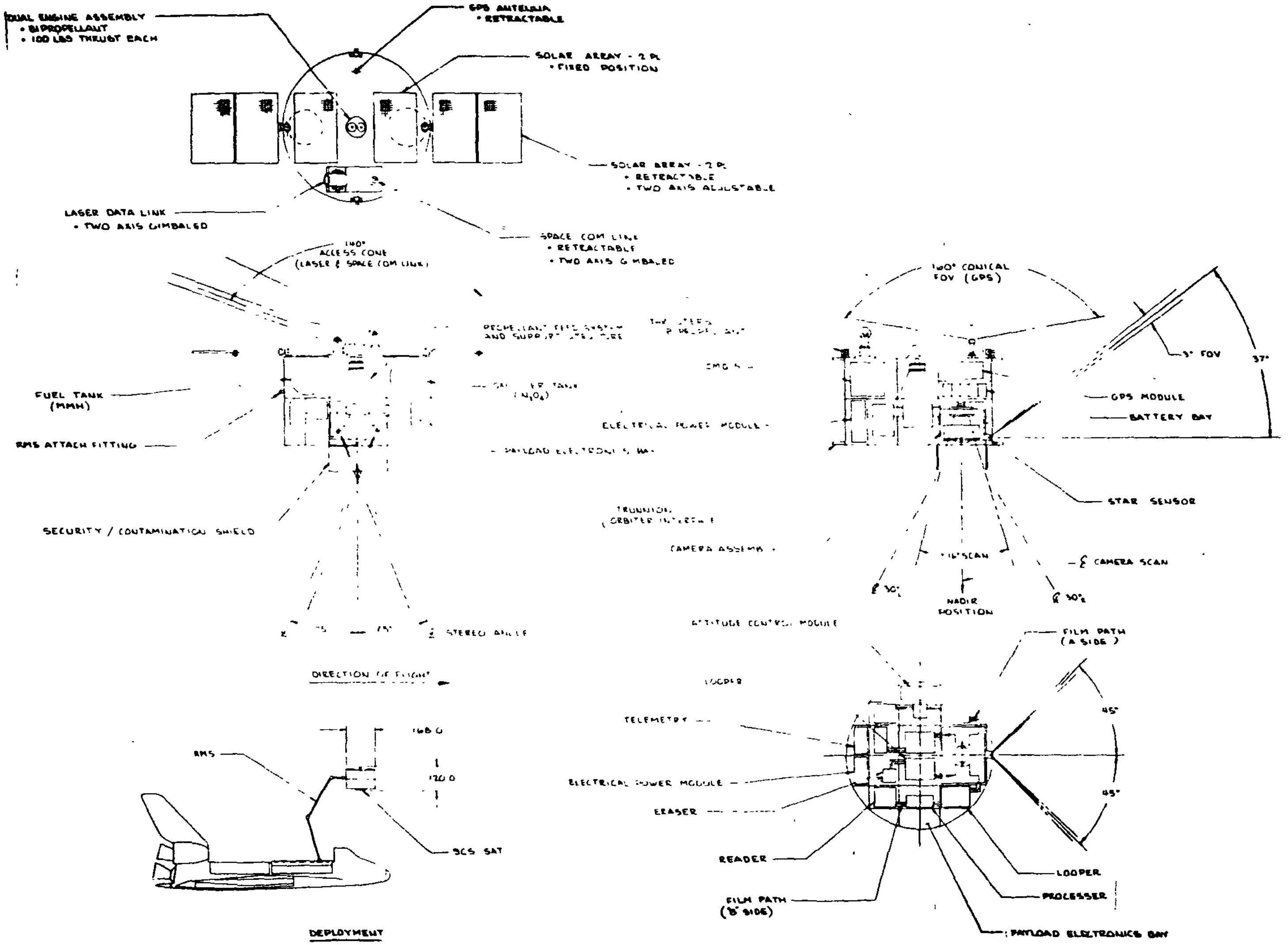
ADVANCED FREE FLYER, CAMERA 2



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PRELIMINARY WEIGHT SUMMARY

The weights shown here were estimated on the basis of similarity to equivalent subsystems on current systems. Major differences are that free flyers require propellant of their own to maneuver and operate for an extended period. The propellant loads shown are for 2-4 years for the interim and about 3 years for the advanced (see page 67). The advanced free flyer, of course, does not require film take up equipment or the film itself. On the other hand free flyers must contain several subsystems that are already available on the shuttle and which the pallet is able to use without having to specially provide.

Note that in keeping with good technique for making preliminary estimates a 20% contingency is included.

PRELIMINARY WEIGHT SUMMARY

ITEM	FIXED PALLET	FREE-FLYERS		
		INTERIM		ADVANCED
		NO. 1	NO. 2	
STRUCTURE AND MECHANISM	1500	1400	1400	1010
CAMERA ASSEMBLY	1300	800	1300	1000
TAKE-UP AND SUPPLY SPOOLS	300	400	690	–
DATA PROCESSING	–	–	–	–
SPACE COMM LINK	–	250	250	250
LASER LINK	–	–	–	300
GPS SYSTEM	–	50	50	50
ELECTRICAL POWER	50	700	700	900
ATTITUDE (INCL CMGs AND RCS)	100	280	280	280
TELEMETRY AND COMMAND	100	150	150	150
PROPULSION DRY	–	400	400	400
CONTINGENCY (20% ABOVE)	670	886	1044	1068
FILM LOAD	700	500	500	–
PROPELLANT	–	1500	1500	3000
TOTAL WEIGHT (LB)	4720	7316	8264	9208

4 OPERATIONAL CONSIDERATION

OPERATIONAL CONSIDERATIONS - INTRODUCTION

There are two basic considerations involved in configuring a system for maximum quantity of take. One is that for complete coverage of high latitude targets and for sun synchronous operation one requires a 97° inclination orbit. The other is that for optimum coverage of dense targets at mid latitudes (50 to 60°N) a lower inclination (e.g., about 57°) is preferred. Closely coupled to these considerations is that 97° inclination flights suffer a significant performance penalty relative to lower inclination flights (orbits such as 57°). This means, especially for shuttle/pallet operations, that less fuel can be taken and mission length is thereby shortened.

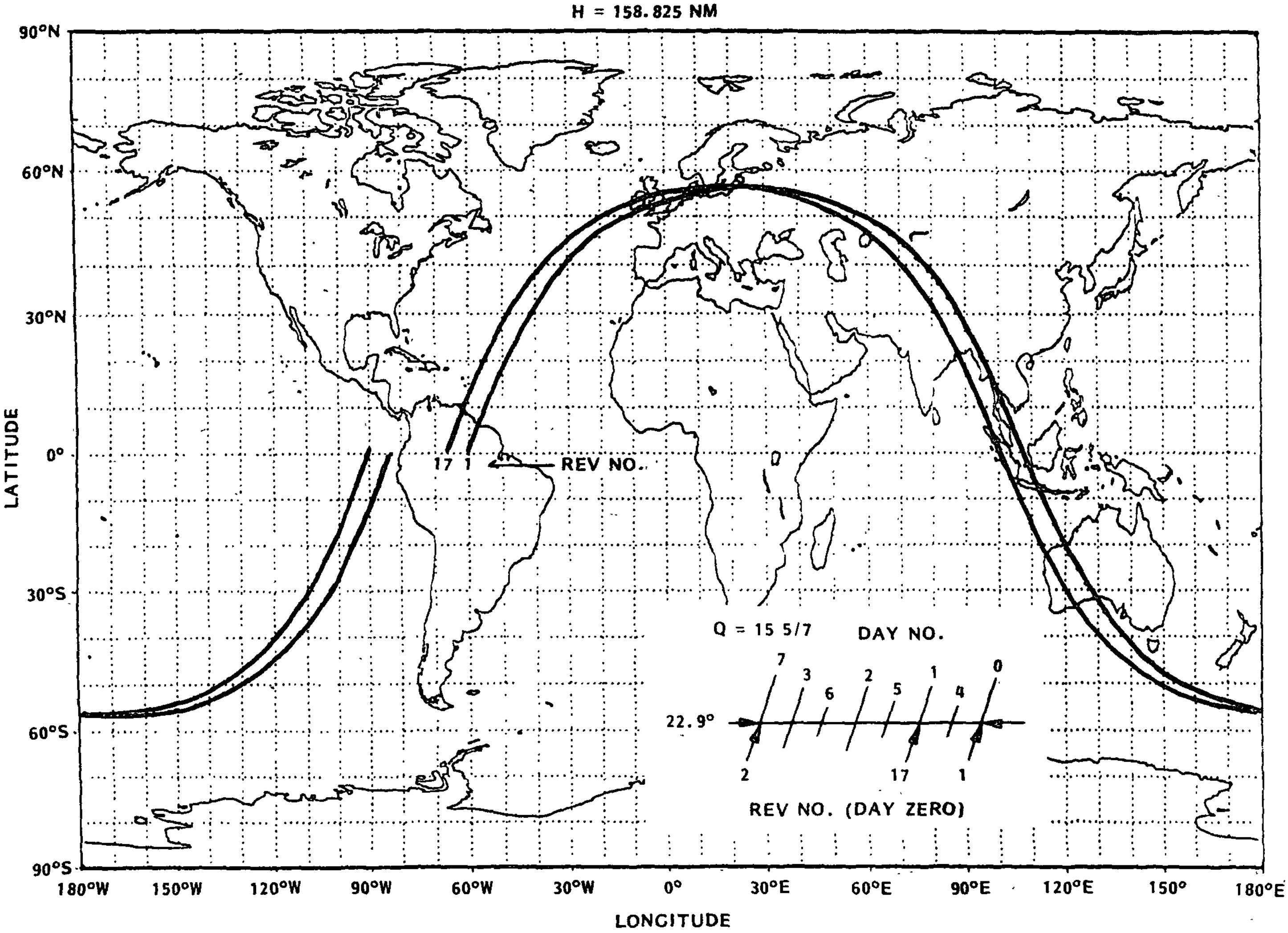
These considerations point out the necessity for some detailed analysis of the operational options and their relative merit. This section addresses several of the more critical operational aspects relating to maximizing take of adequate quality. It concludes with evaluation of the number of access opportunities per mission for the various study systems.

TYPICAL ORBIT TRACE - 57° INCLINATION

For ETR pallets the most practical orbit is about 57° inclination. This is a compromise between efficiency of injection available with a typical shuttle launch and a desire to get high latitude targets. The trace shown is for a circular altitude of about 159 nm. The Q for this orbit is 15 5/7, which means that in seven days the orbiter makes exactly 110 revolutions (orbits) causing the ground track to repeat every seven days.

From the path it is clear that the orbit gives good coverage of targets in the 50 to 60°N latitude region. Thus, although this orbit does not cover all latitudes, it is more efficient than a polar orbit for providing coverage in the latitude band near the value of its inclination. However, the 57° inclination will result in a varying sun angle over the mission life (typically 20 days). This affects the image quality/camera design/smear trades.

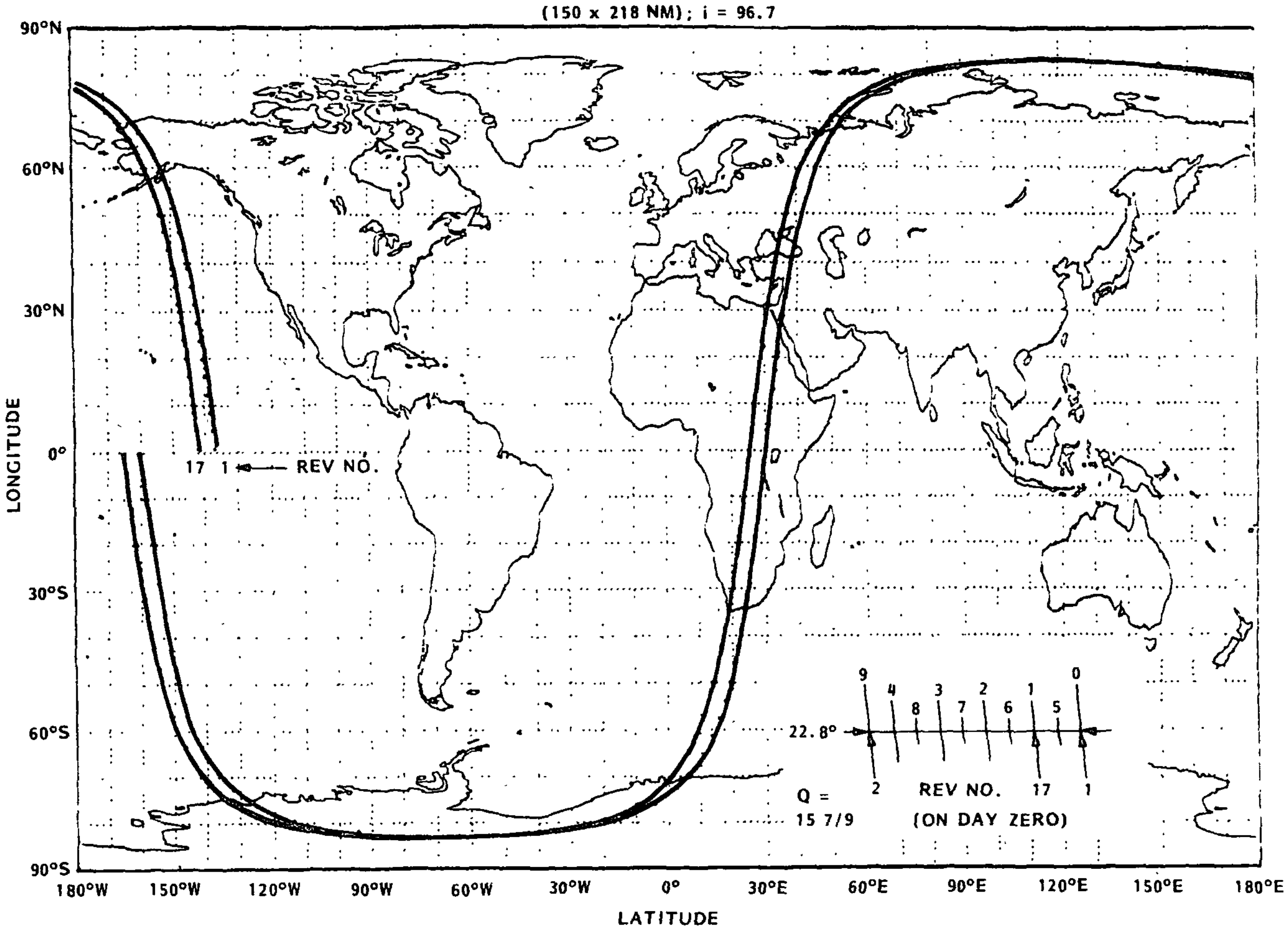
TYPICAL ORBIT TRACE ~57° INCLINATION



SUN SYNCHRONOUS ELLIPTICAL ORBIT

The sun synchronous orbit at 97° inclination has the dual features of providing coverage at high latitudes plus giving a constant sun angle for a given latitude. All passes are essentially north-south (or south-north). For the orbit shown the Q is 15 7/9 which gives a 9 day closure interval. The particular trace is for a 150 (perigee), 218 nm (apogee) orbit. The elliptical orbit is chosen to give as low a perigee as is practical from orbit/maintenance/standpoint in order to give good resolution with SCS aperture optics.

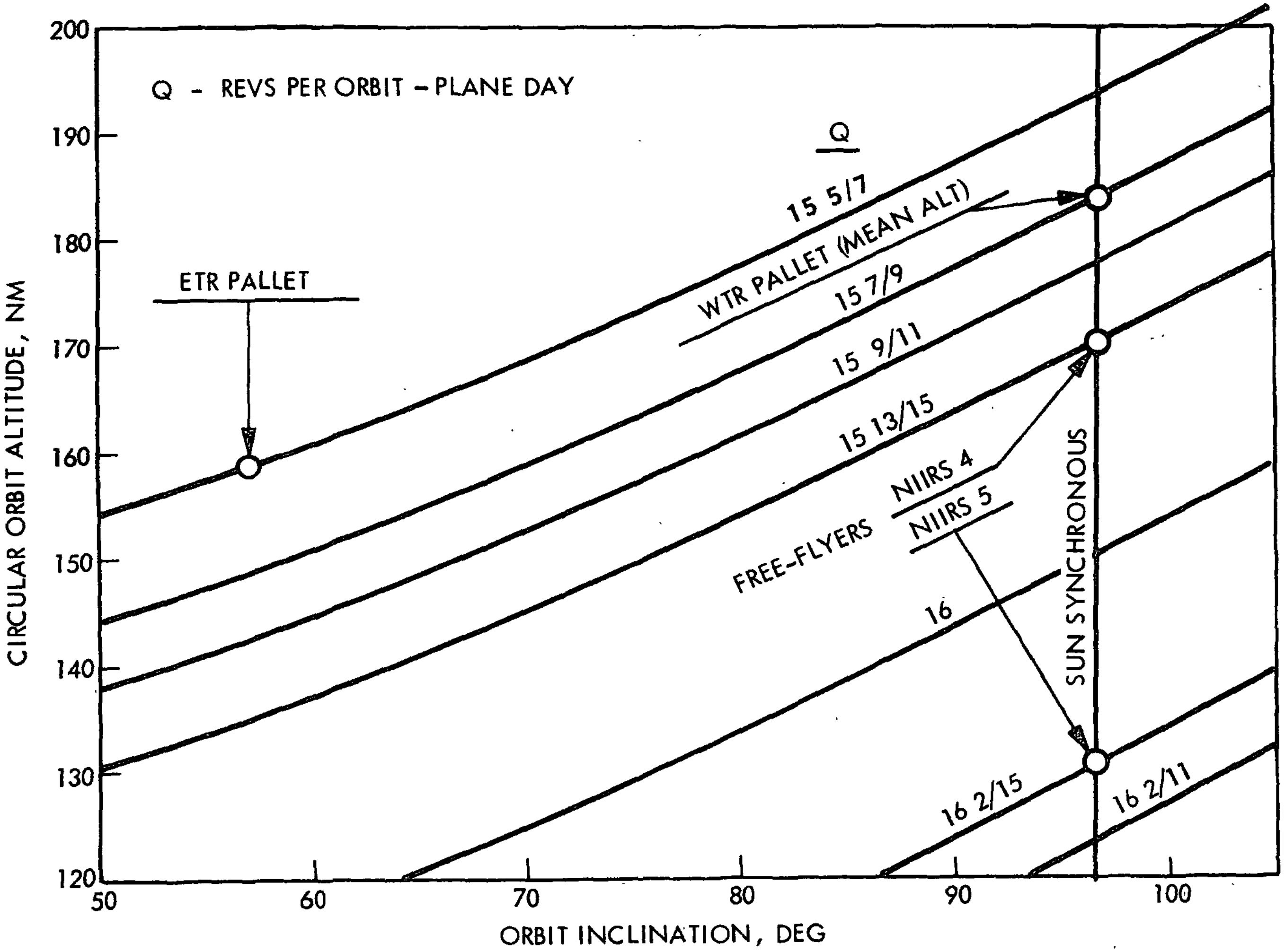
SUN SYNCHRONOUS ELLIPTICAL ORBIT



ORBIT SELECTION PARAMETERS

The accompanying data shows curves of inclination versus period (circular altitude) for various closure periods. (Closure period is the number of days equal to the denominator of the fraction in Q.) Several selected (typical) design points are shown which are a compromise between *quality* and *coverage*.

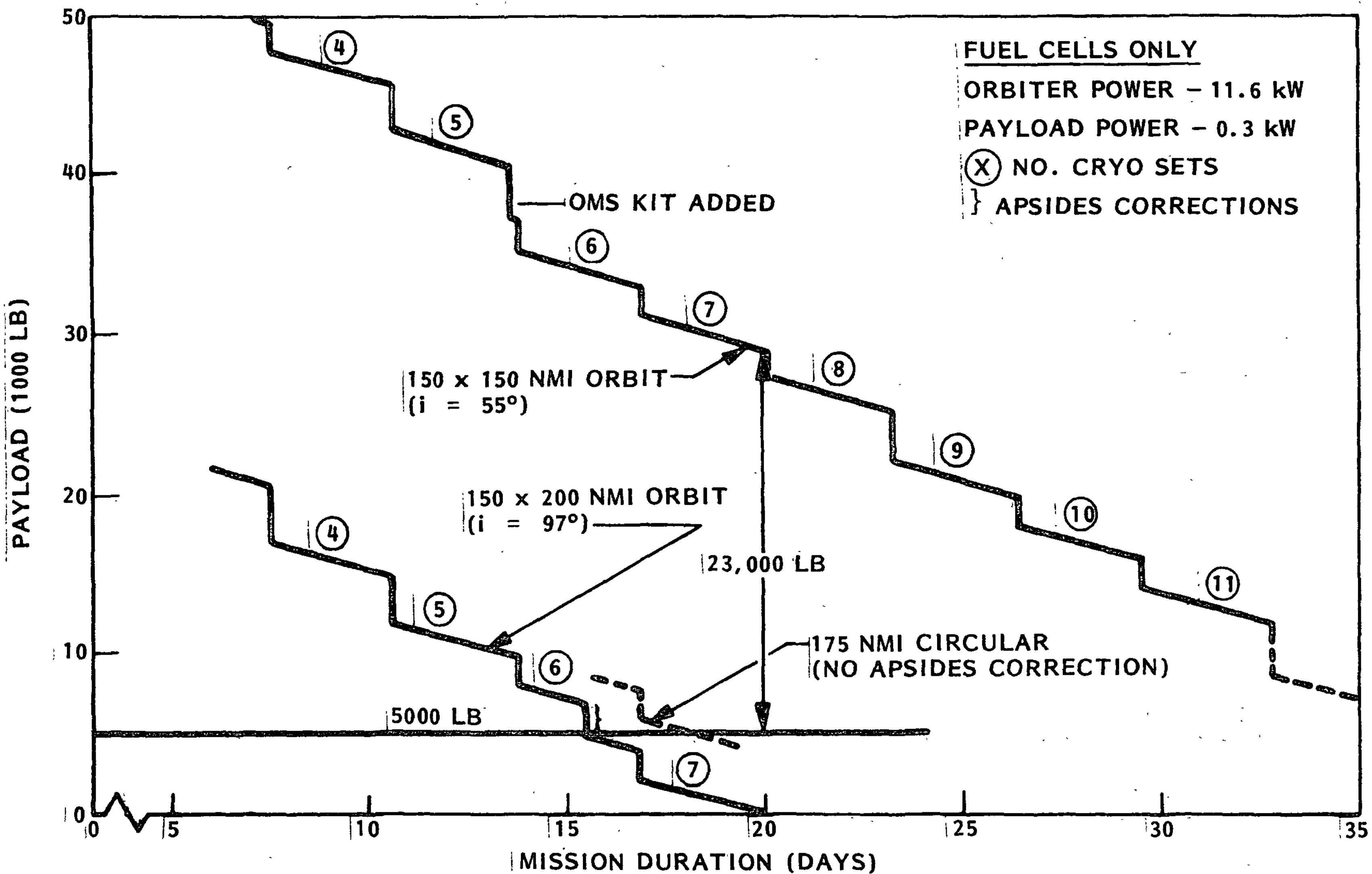
ORBIT SELECTION PARAMETERS



SHUTTLE PERFORMANCE
(FUEL CELLS ONLY)

The accompanying data shows shuttle performance in terms of payload capability vs mission duration. The steps on each curve correspond to the addition of fuel cell tankage. Extra steps on the curve for eccentric orbit are for apsides correction as noted. The upper curve is for ETR launch into i=55° orbit. The lower curve is for WTR launch into i=97° orbit. The difference in the two curves is due primarily to the difference in inclination.

SHUTTLE PERFORMANCE

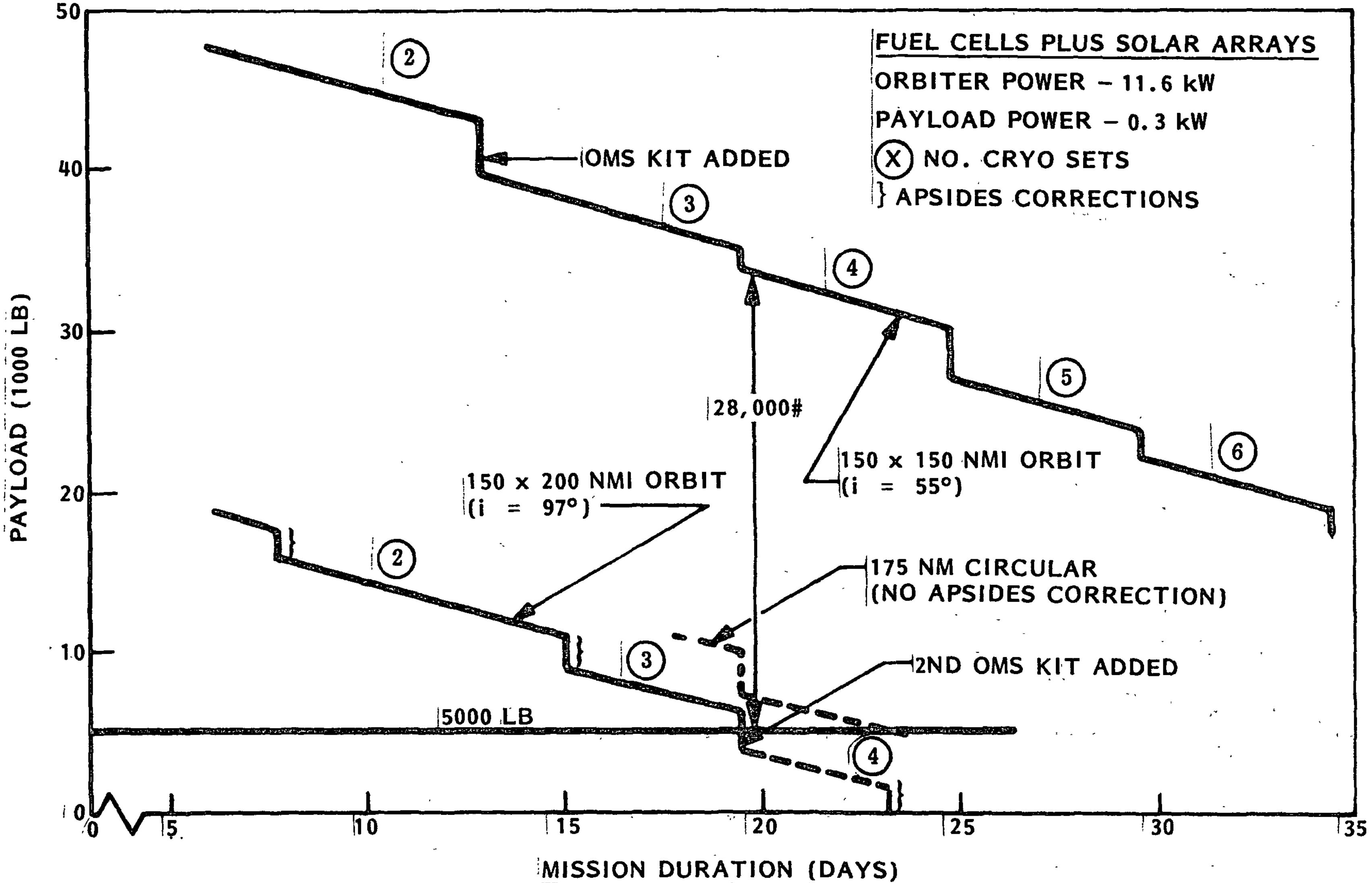


SHUTTLE PERFORMANCE

(WITH SOLAR ARRAYS)

These curves are for shuttle performance with solar arrays added. The net effect is to add about 4 days to the WTR mission or increase the margin on the ETR mission by about 5000 lb. Other characteristics of the curves are similar to those of the previous data.

SHUTTLE PERFORMANCE



STS PAYLOAD CAPABILITY

For the STS Pallet options two mission profiles have been analyzed. One is for a 57° inclination orbit launched from ETR and the other is for a 97° inclination out of WTR. Because of the significant additional ΔV required for the polar (97°) inclination, the STS payload capability is much lower for the WTR launch than for the ETR launch. The accompanying data shows typical weight breakdowns for four different mission/configurations. Note that the injected payload capability out of ETR is nearly twice that from WTR. The effect is manifest in the mission duration that can be supported and even more dramatically in the margin and hence, the possibility of shared payload with other missions.

The numbers shown are best estimate preliminary analysis at this time. STS data was obtained from RI. Some numbers are considered to be softer than others. One of the most uncertain is the requirement of 560.4 lb/day for reaction control system (RCS) propellants. This must be understood better, especially since it amounts to such a large total mission weight penalty.

STS PAYLOAD CAPABILITY

ITEM		CONFIGURATION			
		FUEL CELLS ONLY		FUEL CELLS PLUS SOLAR ARRAYS	
		ETR (57°)	WTR (97°)	ETR (57°)	WTR (97°)
LIFE	TOTAL	22 DAYS	17 DAYS	22 DAYS	19-1/2 DAYS
	OPERATIONS	20 DAYS	15 DAYS	20 DAYS	18 DAYS
PALLET (LB)		5000	5000	5000	5000
ELECT POWER (LB) Ⓧ = CRYOSETS (LB)		11,700 ⑧	7,700 ⑥	5,800 ④	3,800 ③
RCS PROPELLANTS (560.4 LB/DAY)		12,300	9,500	12,300	10,900
OMS KIT (DRY) (LB)		3400	3400	3400	3400
APSIDES (CORRECTION PROPELLANT) (LB)		–	2000	–	2000
TOTAL (LB)		32,400	27,600	26,500	25,100
MARGIN (LB)		21,000	800	17,000	1,400
INJECTED PAYLOAD CAPABILITY (LB)		53,400	28,500	53,500	26,500

TYPICAL PROPELLANT USAGE – FREE FLYER

One concept for the longlife free flyer is to use it in an orbit that will provide NIIRS-4 quality imagery and moderate drag (e.g., 170 nm) for say 10 months per year and then to bring it down to an altitude allowing NIIRS-5 imagery for two months per year. One of the controlling factors in selecting the proper mix is the propellant weight required to provide drag make-up and the orbit maneuvers. Since drag make-up, especially at the lower altitude, is a major factor and since the magnitude of drag varies with sun-spot activity, an analysis was made of the propellant usage (in pounds per day) as a function of time for the 1984 through 1994 time period. From the curves one can see that the rate of propellant required can vary over a significant range. Missions in the 84 through 86 time period will have a clear weight margin advantage over those in the 89 to 90 time period.

The usage values in the accompanying curves were computed from estimates of the effect of sun spot activity on $F_{10.7}$* intensity.

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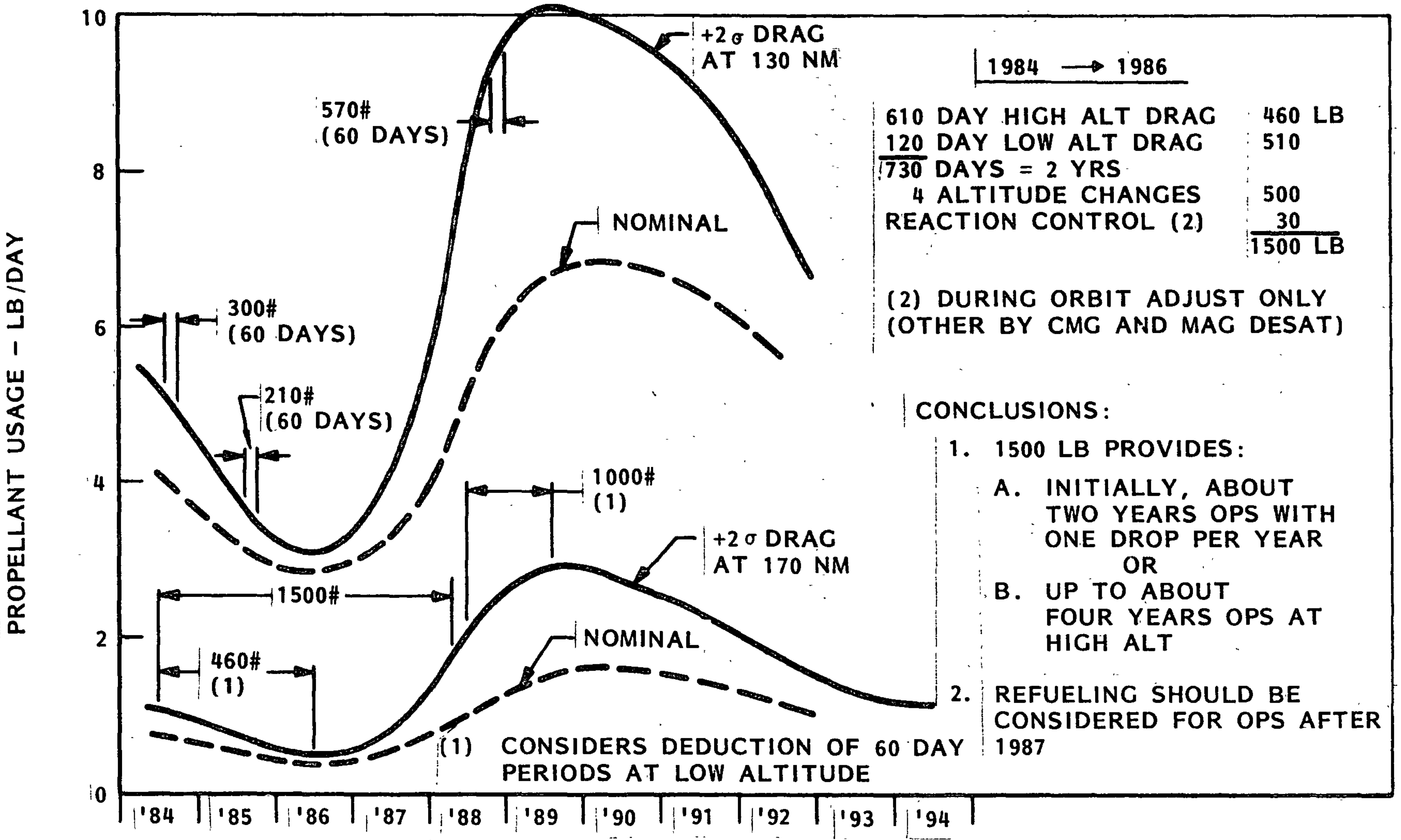
*$F_{10.7}$ refers to the intensity of 10.7 cm solar radiation with which atmospheric density shows a strong correlation.

TYPICAL PROPELLANT USAGE - FREE-FLYER



(1) CONSIDERS DEDUCTION OF 60 DAY PERIODS AT LOW ALTITUDE

1984 → 1986

610 DAY HIGH ALT DRAG	460 LB
120 DAY LOW ALT DRAG	510
730 DAYS = 2 YRS	
4 ALTITUDE CHANGES	500
REACTION CONTROL (2)	30
	1500 LB

(2) DURING ORBIT ADJUST ONLY (OTHER BY CMG AND MAG DESAT)

CONCLUSIONS:

1. 1500 LB PROVIDES:
   - A. INITIALLY, ABOUT TWO YEARS OPS WITH ONE DROP PER YEAR

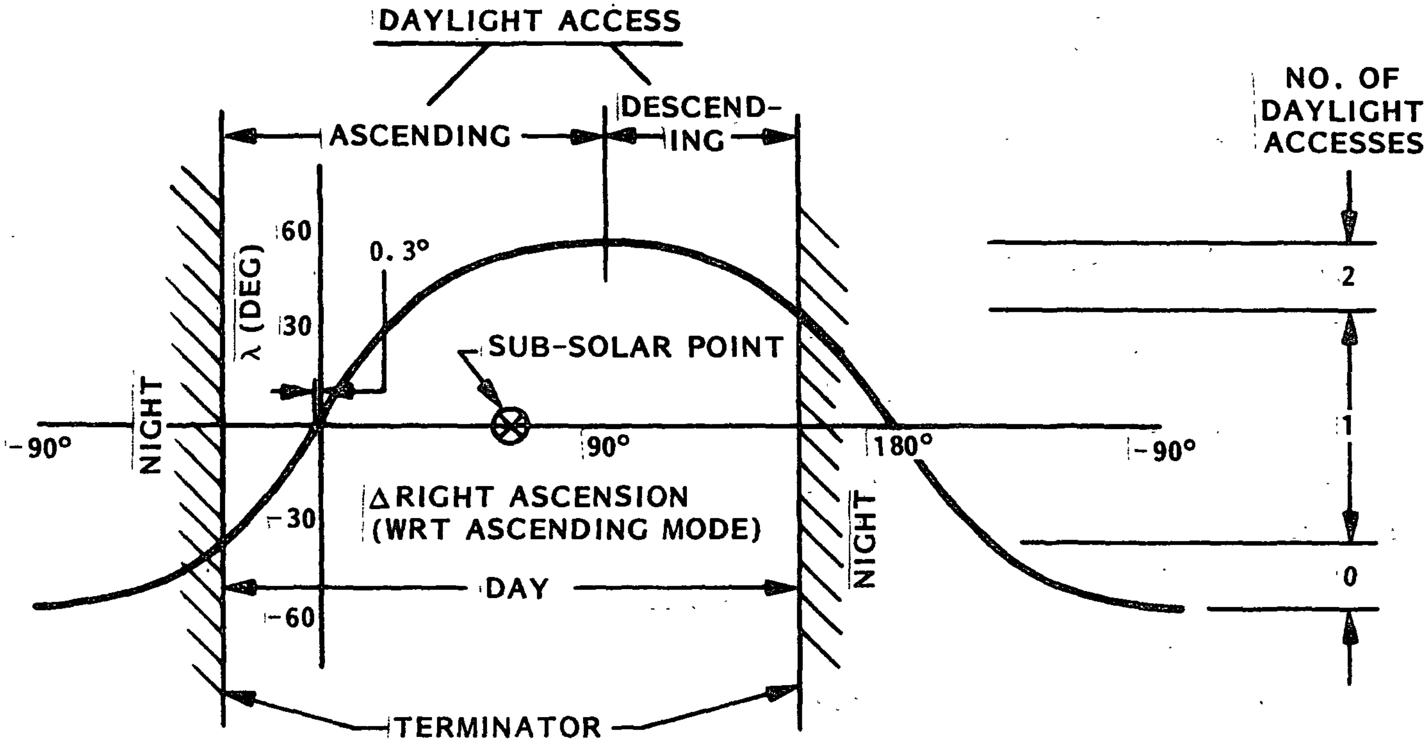
     OR
   - B. UP TO ABOUT FOUR YEARS OPS AT HIGH ALT
2. REFUELING SHOULD BE CONSIDERED FOR OPS AFTER 1987

TYPICAL DAYLIGHT ACCESS -57° INCLINATION

An example is shown here that illustrates the fact that two daylight accesses to targets at a given latitude can occur on a single revolution. A trace is plotted of satellite latitude vs right ascension measured from the ascending node. In these coordinates the subsolar point (taken here at the equinox and 60° east of the orbit's ascending node) remains essentially fixed and the orbit repeats except for a westerly regression of the nodes of about 0.3° per revolution (due to the 57° inclination).

The subsatellite point comes into the sunlight (morning, local time) at about 37° south latitude and has daylight access to targets on the ascending portion of its orbit from that latitude to 57° north. A second access to targets occurs on descending passes from 57° north down to 37° north. The effect, continued over the repeat cycle, is to provide 2 accesses per orbit (in this case, to all target areas between 37°N and 57°N latitude). The variation of the effect with season and the orbit/sun angular relation is presented on the next chart, by plotting the latitude (in this case 37°) of the intersections of the orbit plane and terminator.

TYPICAL DAYLIGHT ACCESS— 57° INCLINATION



DAYLIGHT ACCESS AND ORBIT SUN ANGLE (β)

The latitudes (both north and south) of the intersections of the orbit plane and the plane of the terminator are shown here, plotted as a function of solar longitude as measured from the ascending nodes for four times of year (the two equinox plots are the same). The regions between these curves (and the maximum latitude of 57°) are the locations of single and double accesses per orbit. The value of the sun angle (β) is also plotted.

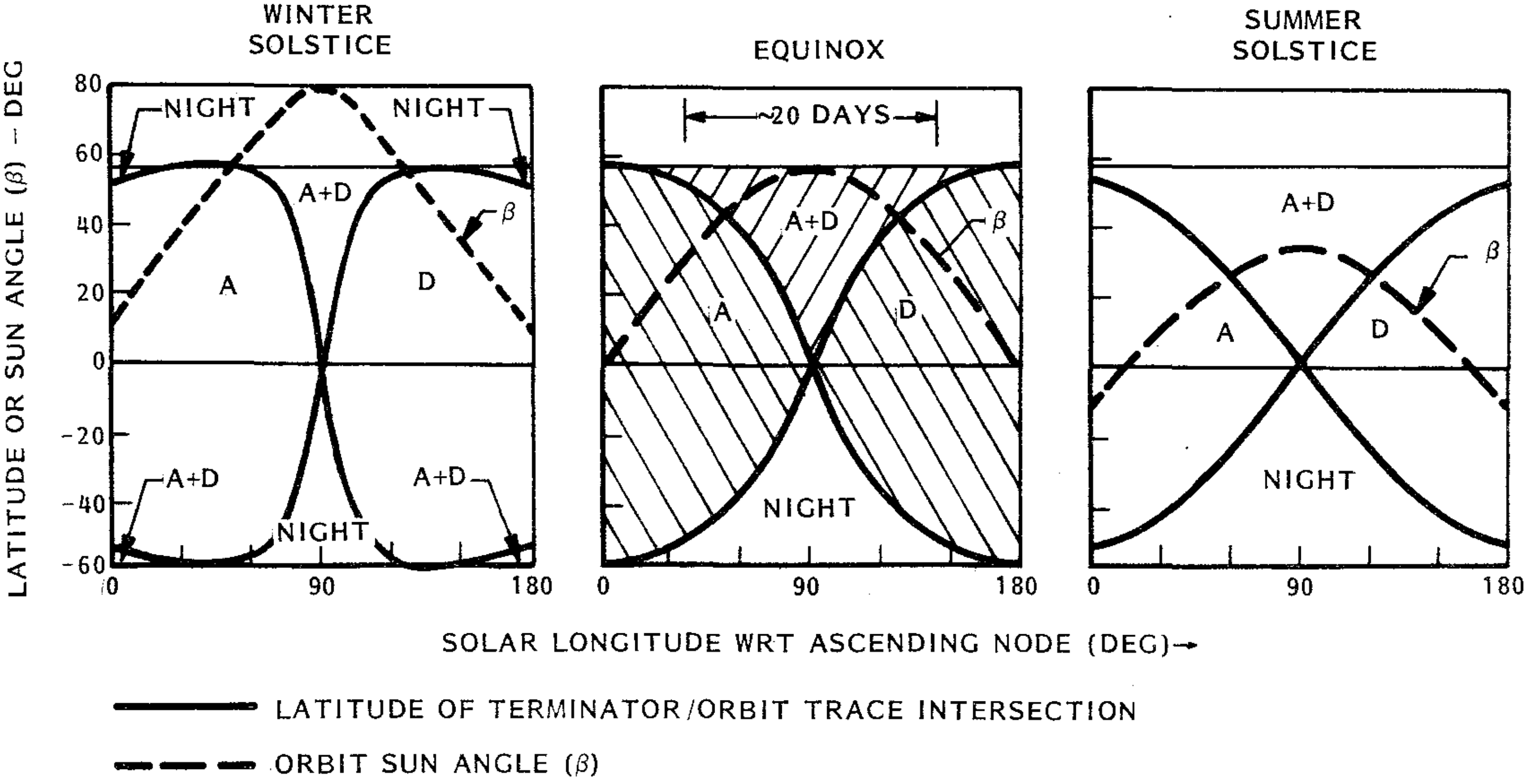
For 159 nm altitude the combined effect of regression of nodes and heliocentric earth rotation cause the value of the abscissa to drift to the right (easterly) at about 5.6°/day. For a 20 day mission the drift typically totals 112° as shown on the center diagram.

For purposes of computing total accesses per mission, it was assumed that launch time was chosen so as to maximize the average number of accesses per orbit. This maximum occurs when the abscissa is 90° at the midpoint of the mission. For winter missions, this may not be the best operating point because of the low value of beta (and resultant poor image quality) and the small improvement in total number of accesses. Quantity performance predictions based on that phasing (presented later) are, thus, slightly optimistic for winter-time operations.

DAYLIGHT ACCESS AND ORBIT SUN ANGLE (β)

57° ORBIT INCLINATION

A&D INDICATE REGIONS OF DAYTIME AT SUBSATELLITE POINT FOR ASCENDING AND DESCENDING PORTIONS OF ORBIT RESPECTIVELY

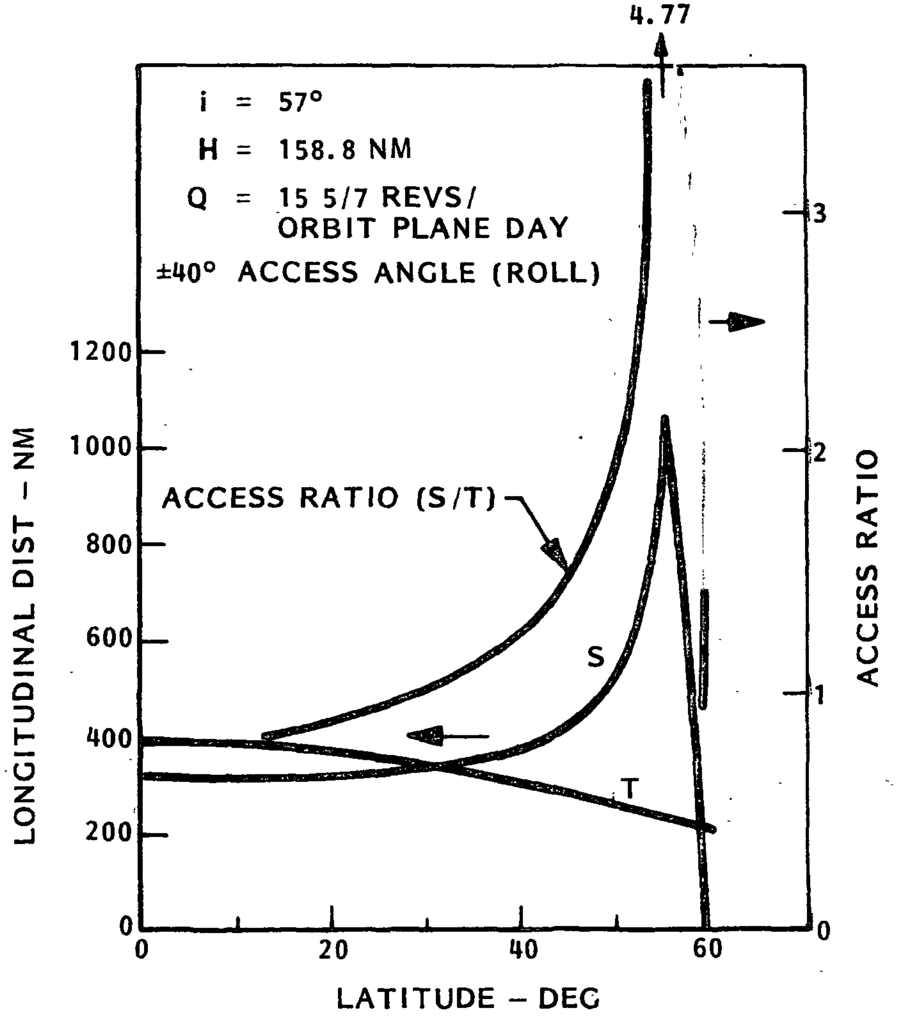


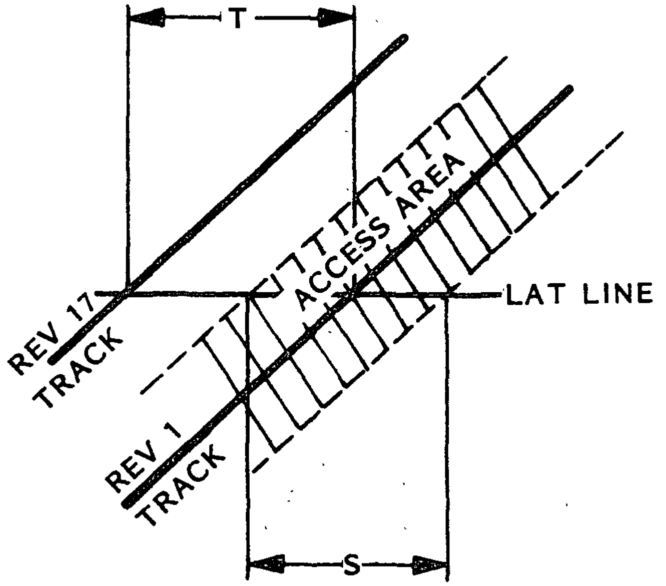
ACCESS RATIO VS LATITUDE

The chart on the right illustrates the definition of the parameters of S (longitudinal swath) and T (track) as used in the access ratio (S/T). T is a function of orbit period, orbit inclination, and latitude. S is a function of SV access angle (roll), vehicle altitude, and latitude. For access ratios of 1 and greater all the area at the latitude is accessable once per day.

The chart on the left shows (longitudinal) swath width as a function of latitude. It peaks at L_m where $L_m = i - \theta$, in which i is the inclination and θ is the earth-central angle from the subsatellite track to the edge of the access swath. The value of θ is the order of 2° for the scan angles and altitudes of interest. The access ratio S/T peaks at essentially the same latitude as S .

ACCESS RATIO VS LATITUDE



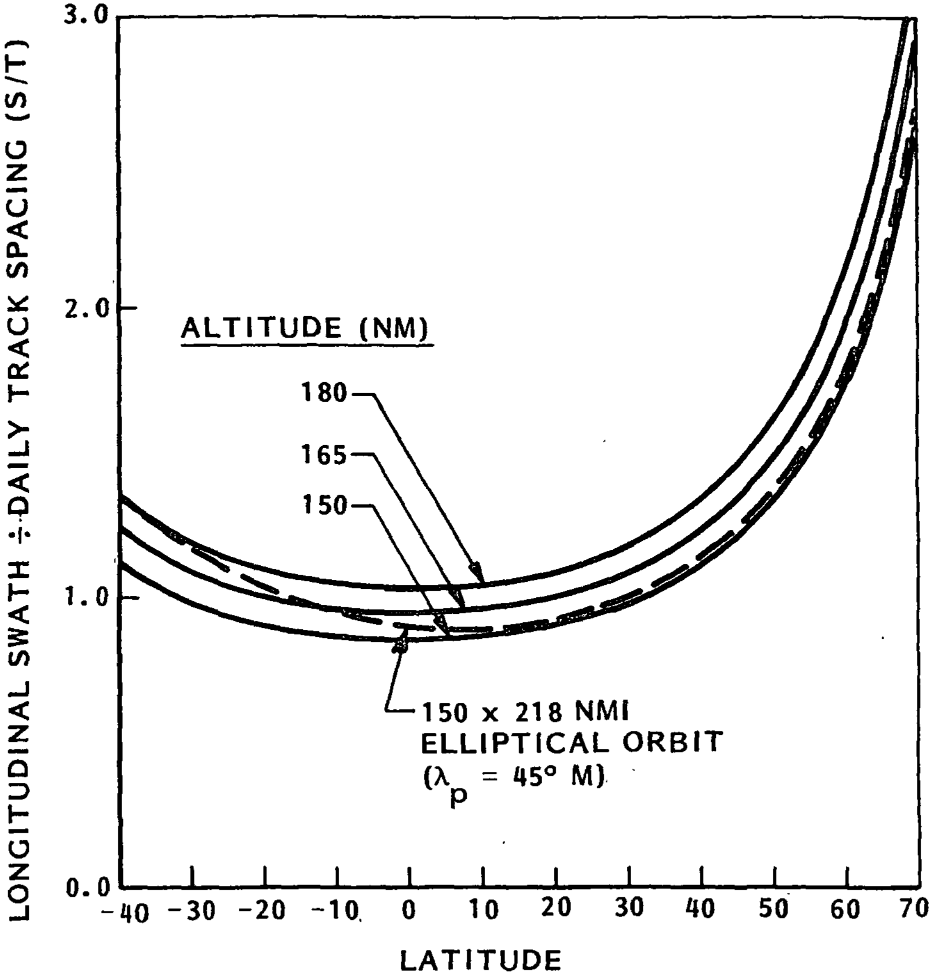


LONGITUDINAL ACCESS RATIO VS LATITUDE

These curves are for 97° inclination with curves for both circular and eccentric orbits. Note that the eccentric orbit is not symmetric around the equator. The swath for these curves is for a maximum access obliquity of ±40°. If the curves were extended out to 90° latitude, the peaks at about 81° would be seen.

LONGITUDINAL ACCESS RATIO VS LATITUDE

97° INCLINATION



ACCESS OPPORTUNITIES

This equation gives N_o the number of daylight imaging opportunities per mission. As can be seen from the data on pp 54-57 , $N_{p/r}$, the number of passes with access in a repeat cycle is typically 2. The number of repeat cycles per mission is, of course, simply the mission duration divided by the closure period. The product of these two factors $N_{p/r} \times N_r$ gives the number of passes with access per mission and is essentially equal to 2 times the number of repeat cycles per mission. This product is essentially independent of latitude. The next two factors $N_{a/o}$ and S/T are both dependent upon latitude. Specifically they both increase with latitude up to the latitude near the orbit inclination.

The product of these four factors gives the number of daylight accesses to a given area during a mission. Note that this number increases with latitude up to the latitute equal to the inclination of the orbit. The controlling variable is longitudinal swath width vs latitude.

ACCESS OPPORTUNITIES

DENSE AREA FORMULATION

$$N_o = N_{P/R} \times N_R \times N_{A/O} \times (S/T) = \text{OPPORTUNITIES/MISSION}$$

WHERE

$N_{P/R}$ = NO. OF PASSES WITH ACCESS PER REPEAT CYCLE

= 2 FOR ALL CASES EXAMINED

$$N_R = \frac{\text{NO. OF DAYS/MISSION (OR SEGMENT)}}{\text{NO. OF DAYS/REPEAT}} = \text{NO. OF REPEAT CYCLES/MISSION}$$

$N_{A/O}$ = AVERAGE NO. OF DAYLIGHT ACCESSES/ORBIT

$$= 1 + \frac{\text{NO. OF DOUBLE ACCESSES}}{\text{TOTAL NO. OF ORBITS}}$$

(S/T) = ACCESS SWATH ÷ DAILY TRACK SPACING

ACCESS OPPORTUNITIES (AND E-W ACCESS)

The number of accesses per mission provided by four different systems is shown. The 20 day duration is a typical value for the ETR pallet; it could be flown slightly longer if needed. The WTR pallet is limited to about 18 days of operation by shuttle performance on a dedicated flight even using solar panels for power augmentation. Sixty days "mission duration" has been assigned to free-flyers (including hexagon) because of the two month, minimum required, repeat interval for imagery. Results for the ETR pallet are a function of season as well as latitude since the average number of daylight accesses per orbit on the 57° orbit is greater in summer than winter.

These data provide the basic operational information, to be combined with weather information, to compute system quantity performance as discussed in Section 5, Performance Analysis. The width of access in an east-west direction is also shown for each latitude since it also influences quantity performance.

A preliminary comparison can be made among the systems from these data. For instance, it is clear by comparing the ETR pallet to hexagon that it will perform very well at 50° latitude, even on a 20 day mission, while it will be more limited at lower latitudes.

ACCESS OPPORTUNITIES (AND E-W ACCESS)

		LATITUDE			
		0°	25°	50°	60°
ETR PALLET, 57° INC., 159 NM					
±40° ACCESS, 20 DAYS	WINTER SOLSTICE	4.5	5.8	14.3	0.0
	EQUINOX	4.5	6.9	21.3	0.0
	SUMMER SOLSTICE	4.5	8.1	22.5	0.0
	E-W ACCESS (NM)	(312)	(328)	(499)	
WTR PALLET, SUN SYNCH, 150 x 218 NM, λp ≅ 45°N					
140° ACCESS	18 DAYS	3.7	3.9	5.4	7.9
	E-W ACCESS (NM)	(275)	(261)	(260)	(265)
FREE-FLYERS, SUN SYNCH					
±40° ACCESS, 60 DAYS	170 NM, 2 SATS	25.6	28.5	40.5	52.7
	E-W ACCESS (NM)	(292)	(293)	(295)	(299)
	130 NM, 1 SAT	10.0	11.0	15.7	20.4
	E-W ACCESS (NM)	(223)	(223)	(225)	(228)
HEXAGON, SUN SYNCH, 90 x 150 NM, λp ≅ 45°N					
(FOR REFERENCE)	±45° ACCESS, 60 DAYS	9.1	9.4	13.1	17.2
	E-W ACCESS (NM)	(202)	(188)	(186)	(190)

5 PERFORMANCE ANALYSIS

PERFORMANCE ANALYSIS - INTRODUCTION

The study emphasis was on quantity performance rather than quality performance. The desired image quality was shown to be within the range of SCS capability in previous studies by payload contractors. However, the coverage, or total quantity of take, could be inadequate due to the limited mission time which would be available in light of limitations in Shuttle capability to carry enough fuel for extended missions (e.g., more than about 20 days).

PERFORMANCE ANALYSIS SUBJECTS

After summarizing NRO search requirements, specific aspects of the quality question were addressed in a preliminary manner in the areas indicated on the chart. Following discussion of these areas, an extensive discussion of the quantity performance analysis is provided in this section. Additional detail is also provided in the appendix.

Finally, a performance analysis summary states the conclusions which contribute to major study results.

PERFORMANCE ANALYSIS SUBJECTS

REQUIREMENTS

QUALITY PERFORMANCE
- SMEAR DUE TO VEHICLE RATES
- GRD (NADIR AND AWAR) VS ALTITUDE
- MC&G LOCATION ACCURACY

QUANTITY PERFORMANCE
- METHODOLOGY
- WEATHER DATA
- PRELIMINARY QUANTITY PERFORMANCE ESTIMATES

PERFORMANCE ANALYSIS SUMMARY

PRELIMINARY 1985-90 STANDING SEARCH REQUIREMENTS

This chart summarizes the data provided by SP-6 as the requirements basis for the SCS study. The stated requirement is that 80% of the areas shown, in millions of square nautical miles (MSQNM) are to be imaged at the intervals and with quality shown.

Data at a 2 month interval is limited in quantity to only 180,000 sq nm. However, much of this area is concentrated in limited regions, principally, Europe, Western USSR and parts of Southeast Asia. These have been taken as the dense target areas which drive the performance capability to be provided by the SCS system.

The value of 60.19 MSQNM for imagery considers the effect of two images being required in the stereo mode. This value is used as a basis for estimation of film quantity requirements.

PRELIMINARY 1985-90 STANDING SEARCH REQUIREMENTS

	MSQNM	REQUIRED NIIRS	IMAGING MODE*
2 MONTH	0.18	4 (50% ≥ 5)	S
4 MONTH	1.07	3 (80% ≥ 4)	S
6 MONTH	0.75	3 (80% ≥ 4)	S
9 MONTH	12.99	3 (80% ≥ 4)	S
12 MONTH	3.62	3 (80% ≥ 4)	S
18 MONTH	15.22	3 (80% ≥ 4)	M
24 MONTH	7.75	3 (80% ≥ 4)	M
TOTAL	41.58		
AREA PER YEAR (100% SATISFACTION)	40.75	IMAGERY PER YEAR 60.19 (100% SATISFACTION)	

* S = STEREO REQUIRED
M = MONO ACCEPTABLE, STEREO PREFERRED

SMEAR DUE TO VEHICLE RATES

Smear of the image is caused by relative motion of the scene relative to the film. Thus any vehicle angular rate that is not compensated by appropriate adjustment of the film motion can cause smear. There are two ways that unwanted vehicle rates can be generated. One is directly as a result of an (unknown, uncompensated) residual/angular rate about any vehicle axis (relative to an earth fixed coordinate system). Another is due to the cross coupling effect of known rate about one axis being coupled into another axis due to an unaccounted offset about the third axis. Thus, in the presence of a known pitch rate an unknown offset about the yaw axis produces an unknown and, hence, uncompensated rate about the roll axis causing cross track smear.

Residual rates about any axis are a function of the tightness and quality of the attitude control system. Factors that affect the residual rates are characteristics of the control limit cycles and drift rate of the control gyro(s) or other attitude control sensor. For large vehicles, vehicle bending can also cause noticeable residual rates. As a practical matter residual rates in the STS can be held below numbers like 0.01°/sec about any axis. For a smaller free flyer residual rates can easily be held to below 0.005°/sec.

With appropriate reference gyros situated close to the camera it is easy to keep unknown angular offset to an acceptably low value. However, from a cost and complexity standpoint it would be desirable in the pallet concept to utilize the STS control system without augmentation or necessity for dedicated payload attitude reference. There is a potential problem in that quoted angular uncertainties for the STS are too large by about a factor of four. However, preliminary analysis indicates that with the help of onboard calibration the uncertainties in the STS attitude system (gyros) can be reduced to an acceptable value (i.e., to the order of ¼ to ½°). The accompanying data shows the smear due to uncompensated vehicle rates for both the STS pallet and the free flyer. It can be seen that the total RSS smear due to these effects is acceptable in light of nominal requirements to keep the total smear to less than 400 μrad/sec.

SMEAR DUE TO VEHICLE RATES (20° STEREO CONV)

ANGLE	PALLET (PROPOSED REQUIREMENTS) IN 150 NM ALTITUDE				REASONABLE FREE-FLYER CAPABILITY 120 NM			
	ONE SIGMA ERROR	WORST CASE COMPONENT SMEAR (μR/S) / PAN ANGLE		WORST CASE TOTAL RSS 20° PAN (μR/SEC)	ONE SIGMA ERROR	WORST CASE COMPONENT SMEAR (μR/S) / PAN ANGLE		WORST CASE TOTAL RSS 0° PAN (μR/SEC)
		IN-TRACK	X-TRACK			IN-TRACK	X-TRACK	
YAW	0.25°	NEGLIGIBLE	117/0°	102	0.1°	NEGLIGIBLE	59/0°	59
PITCH	0.5°	81 (0°)	110/40°	104	0.1°	20/0°	28/40°	20
ROLL	0.5°	NEGLIGIBLE	42/0°	30	0.1°	NEGLIGIBLE	11/0°	11
		TOTAL RSS (1σ)		149		TOTAL RSS (1σ)		63

RATE	PEAK RESIDUAL (DEG/SEC)	SMEAR (μR/S)			PEAK RESIDUAL (DEG/SEC)	SMEAR (μR/S)		
		PEAK IN-TRACK COMPONENT	PEAK X-TRACK COMPONENT	RSS SMEAR		PEAK IN-TRACK COMPONENT	PEAK X-TRACK COMPONENT	RSS SMEAR
YAW	0.01	25	25	25	0.005	13	13	13
PITCH	0.01	175	NEGLIGIBLE	111	0.005	88	NEGLIGIBLE	62
ROLL	0.01	NEGLIGIBLE	175	111	0.005	NEGLIGIBLE	88	62
		RSS:		159		RSS:		89
		RSS TOTAL:		218μR/SEC		RSS TOTAL:		109μR/SEC

SCS QUALITY PERFORMANCE

This chart presents quality performance estimates based on data provided in the SCS report by EK. These results assume a vehicle smear contribution of 400μR/S, a 40° sun angle and use of 1414 film. The camera assumed is the Camera No. 1 design, based on obtaining 0.8 meter GRD on axis at nadir from 150 nm altitude. The upper curves also take into account the average effects of geometric smear across the image format with operation providing a 20° stereo closure angle.

Based on available data, cross-over from NIIRS 5 to NIIRS 4 imagery is about 30 inch GRD, though it may vary over a considerable range depending on other image characteristics produced by such factors as the MTF curve shape, haze, transmission and smear. It can also be affected by subjective factors inherent in the assignment of NIIRS ratings. Currently proposed models to improve prediction of NIIRS (based on predictable image characteristics) appear to have limited applicability to new systems. More detail in this area is provided in Appendix D.

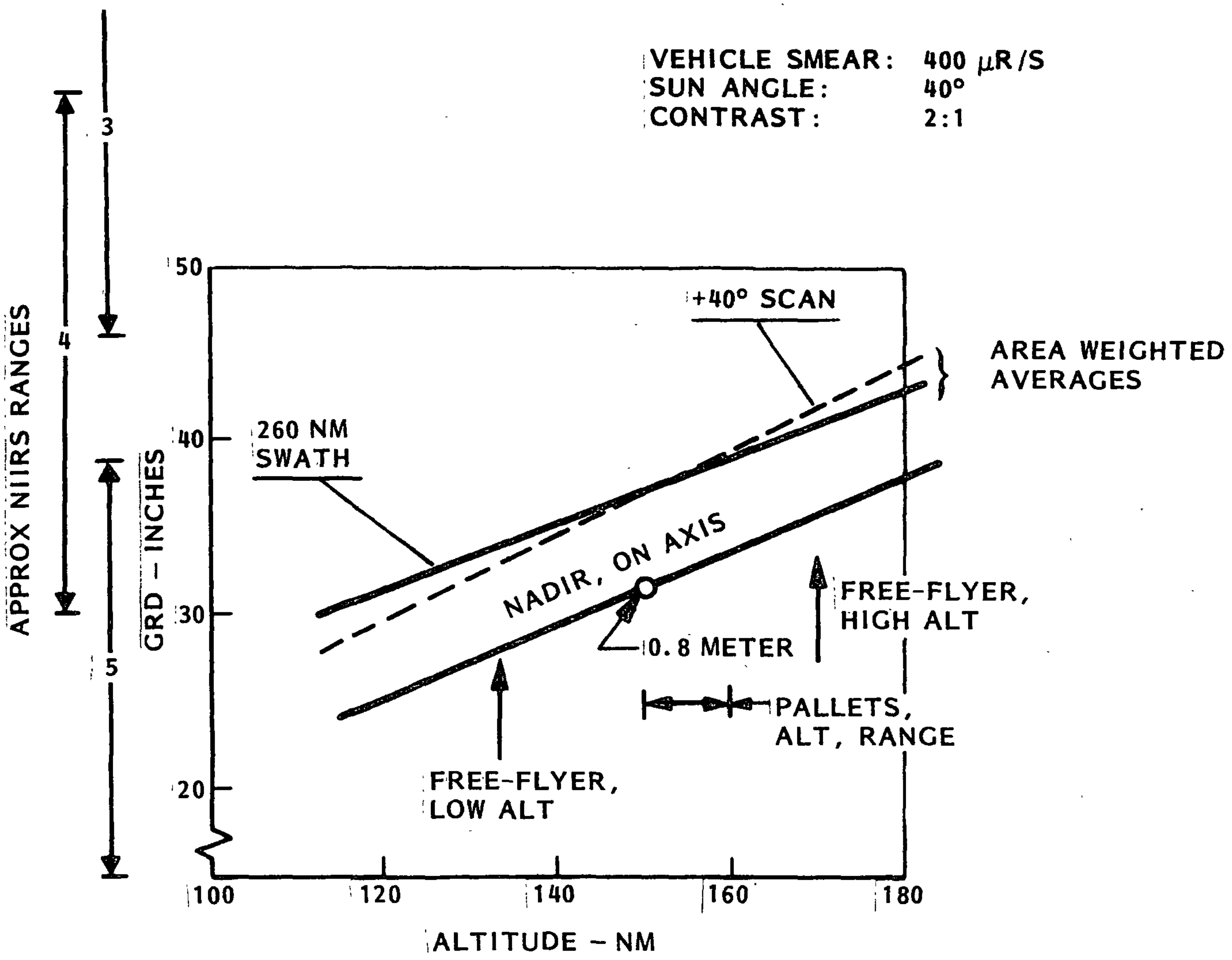
Using the 30 inch criteria, it would appear that the current SCS designs should be modified somewhat to match image quality requirements. For pallets operating in the altitude range of 150 to 160 nmi, an appreciable increase in aperture is indicated for two reasons: (1) to obtain some NIIRS 5 imagery and (2) to provide for the impact of low average sun angles in the case of the ETR pallet. For free-flyers, an aperture increase of about 13 percent would provide NIIRS 4 performance at 170 nm equivalent to that shown here at 150 nm and would assure an adequate proportion of NIIRS 5 imagery at 130 nm altitude.

An alternate performance improvement approach would use available high resolution films instead of 1414 film ground-ruled for these predictions.

The most severe impact on aperture derives from the NIIRS 5 pallet requirement. If this requirement were relaxed (as is implicit in the study recommendation to delete the "2 month take" requirement from interim SCS requirements), it is likely that a single camera design, applicable to both pallets and free-flyers, can be developed. A compromise focal length is implied since a faster system would be appropriate for ETR pallets, to accommodate the lower average sun angles experienced in the 57° orbit. A realistic evaluation of such a design concept will require a sophisticated haze and transmission model as well as a smear model. Recent operational experience has shown that a sample of standard CORN targets having 7 and 33 percent reflectance (4:75:1) have an apparent (entrance pupil) contrast of 2:1 for sun angles of 50° to 55°, while contrasts in the range of 1.2:1 to 1.4:1 occurs for sun angles from 5 to 20°. Image quality at low sun angles will be significantly affected by low contrast as well as by the additional smear effects with increased exposure time.

SCS QUALITY PERFORMANCE

VEHICLE SMEAR: 400 μR/S
SUN ANGLE: 40°
CONTRAST: 2:1



MC&G LOCATION ACCURACY

From various sources it has been concluded that MC&G requirements call for earth point location accuracy of the order of 25 ft, 1 sigma, in all three directions. There has been some indication that location accuracy as good at 15 ft would be desirable. Since the sources for these requirements have not been verified – in terms of the justification for the requirements/desirements – our approach has been to treat these accuracies as ball-park requirements and to identify the capabilities available to provide the approximate level of performance. Roughly speaking, it appears that 1986 state-of-the-art (SOTA) technology will come close to providing the 25 ft location accuracy in realtime (on the primary record) and the 15 ft accuracy on the ground in a post-pass (non-real time) mode.

The approach taken to identify a system concept for obtaining the desired performance was to establish a nominal error for the elements of the general type of system indicated and to see if an implementation were available within the SOTA.

Two basic elements of information are necessary to establish the location of earth points on satellite imagery. They are a knowledge of the satellite position in an earth fixed coordinate system and a knowledge of the camera optical axis (line of sight) orientation in the same earth fixed coordinate system. Because of the extreme accuracy required, the only feasible way of obtaining the LOS orientation is to measure vehicle or camera orientation relative to the stars and to tie that to an earth fixed coordinate system by means of an accurate ephemeris. To accomplish this in real time, especially to provide target location information on the primary record requires that the ephemeris be available onboard the satellite in real time. This suggests the use of the NAVSTAR GPS for satellite ephemeris determination as the only practical implementation.

With a system of satellite mounted star sensors for attitude and the GPS for ephemeris the following error sources must be considered.

- Satellite Position (ephemeris) uncertainty
- Star sensor uncertainty
- Star sensor – camera boresight alignment/calibration
- Satellite angular rate uncertainty

The allocations in the chart appear reasonable. The driver is probably the GPS capability. It is expected that the capability of this system, especially, will improve between now and the late eighties. Hence, three different budgets are shown as a function of time. The goal may only be achievable with the use of post pass (non real-time) techniques.

BIF003W/2-165321-79
REV A

MC & G LOCATION ACCURACY

ERROR BUDGET

NO.	SOURCE	1σ POSITION UNCERTAINTY			
		ANGULAR (μRAD)	LINEAR (FT) AT 167 NM		
			1984	1986	GOAL
1	GPS (REAL TIME)	NA	50	15	10
2	STAR SENSOR	10	15	10	5
3	STAR SENSOR/CAMERA LOS UNCERTAINTY	10	15	10	5
4	VEHICLE RATE UNCERTAINTY	10	15	10	5
5	GROUND CALIBRATION POINTS	–	15	10	5
TOTAL (RSS)		NA	60	25	15

QUANTITY ANALYSIS METHODOLOGY

The important conclusion of a preliminary analysis was the validity of using a 250 nm target strip in the definition of P(≥1) (defined on chart) as a meaningful measure of mission success. This analysis, based on weather data from previous studies, examined the sensitivity of P(≥1) to the target strip width considered (while not differentiating between imaging swath and access swath). The resulting low sensitivity above 250 nm is compared on a subsequent chart to results of the refined analysis, which used the 250 nm value throughout.

The use of the 60% cloud free threshold is based on the fact that images taken under these conditions are, on the average, over 80% cloud free, an appropriate value since requirements are based on obtaining 80% coverage of defined target areas at specified intervals. All five 50 nm cells in a 250 nm strip must be imaged under such conditions to meet these requirements, since missing one cell would cause the total return to fall below 80%. This conclusion implicitly assumes a "dense target area", i.e., that there are target regions of interest in each of the 50 nm wide cells. The use of 50 nm for cell size is justified by two considerations: (1) 50 nm in a reasonable lower limit for panoramic scanning (~15° to ~30° scan angle, for altitudes ranging from 170 nm down to 90 nm) and, (2) a standard grid spacing for historical weather data is 50 nm. Thus, the probability of being able to image all 5 cells at least once during a mission (or for free-flyers, during a mission segment of 60 days, the smallest required repeat interval) is used as the principal measure of system quantity performance.

Dense areas were selected, specifically Moscow, Europe 50°N-15°E, USSR 51°N-41°E, and south China 25°N-110°E, and the Air Force air weather service, located at the STC, provided the weather statistics based on four years of weather data. The weather patterns were comprised of 5-50 nm cells in the 250 nm strip; consequently, there were 32 discrete weather patterns. Another factor evaluated was the effect on system performance of the limited (±16°) scanning capability of the initial SCS camera designs, which results in an imaging swath less than the 250 nm access swath. Consequently, an access screening matrix was used to compute the pass transition matrix for the cases when the imaging swath was less than the 250 nm target strip. The system performance under this condition is highly dependent on spatial correlation of the weather patterns i.e., the likelihood of the weather being clear over various widths greater than the 50 nm cells.

Using stochastic process analysis, pass transition probability matrices were constructed that enable the computation of the success probability (P≥1) after each successive access. From these data, parametric curves of P(≥1) vs access opportunities were generated. For each target area there are three parameters that affect success on a per pass basis (1) probability of ≥60% cloud free weather for a random grid point (cell), (2) spatial correlation implicit in the data for the 32 weather patterns, and (3) imaging swath width. To determine the value of P(≥1) for a given mission, this is combined with the number of access opportunities during the mission computed from the five parameters indicated. Specifics on these computations are covered in Section 4, Operational Considerations.

The final data computed considers cases for both poor weather and moderate weather for the short life pallet systems and compares their capability to that of free-flyers. An additional performance parameter compares these results to *hexagon* capability, as predicted by the same analysis normalized for a 60 day segment of its mission.

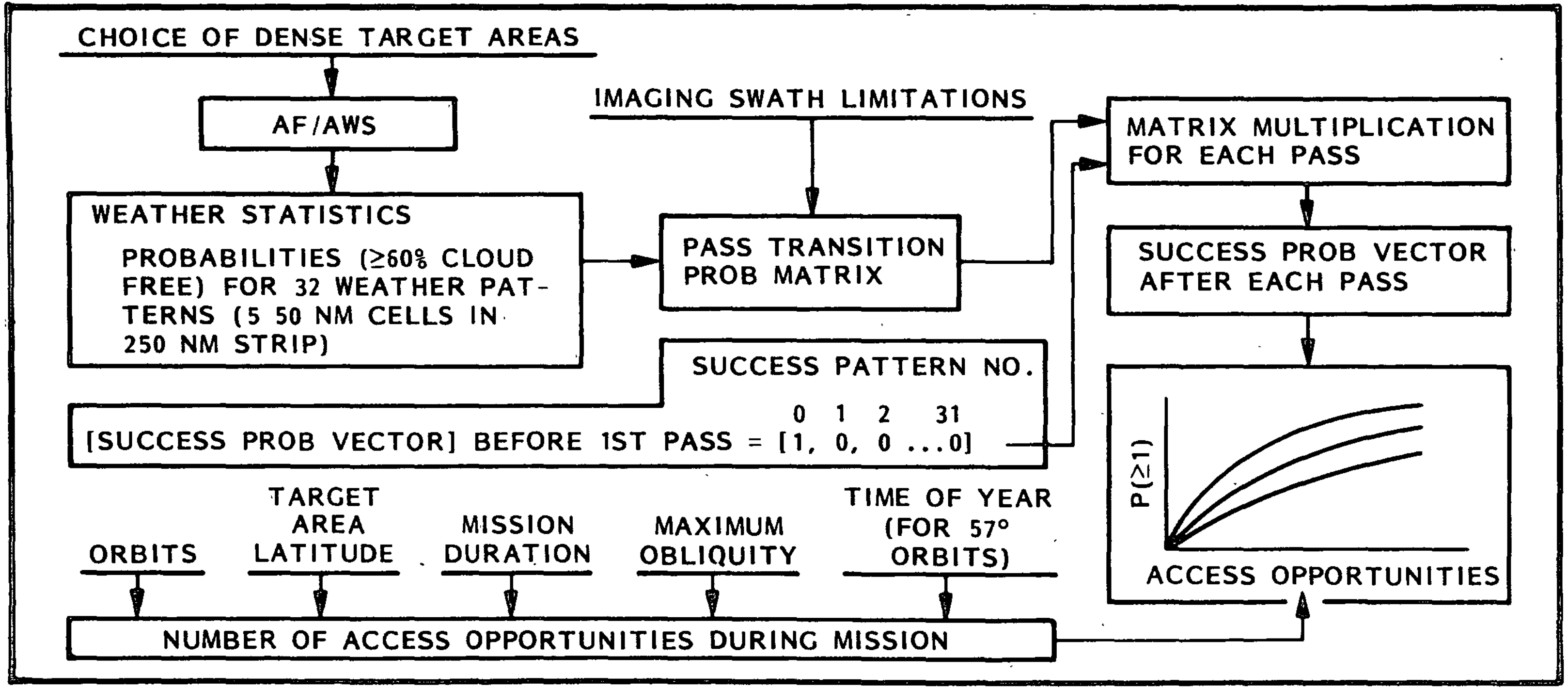
QUANTITY ANALYSIS METHODOLOGY

PERFORMANCE CRITERIA

- PROBLOOK = 0.1
- PRELIMINARY SPATIAL CORRELATION CURVE
- PRELIM ANALYTICAL MODEL
- PARAMETRIC WIDTH OF TARGET AREA STRIP

CONCLUSION: A MEANINGFUL MEASURE OF QUANTITY PERFORMANCE IS: P(≥1) = PROBABILITY OF AT LEAST ONE LOOK, WITH ≥60% CLOUD FREE WEATHER, AT ALL PORTIONS OF A 250 NM EAST-WEST STRIP IN TYPICAL DENSE TARGET AREAS.

REFINED ANALYSIS – COMPUTATION OF P(≥1)



CHOICE OF DENSE TARGET AREAS

AF/AWS

WEATHER STATISTICS

PROBABILITIES (≥60% CLOUD FREE) FOR 32 WEATHER PATTERNS (5 50 NM CELLS IN 250 NM STRIP)

IMAGING SWATH LIMITATIONS

PASS TRANSITION PROB MATRIX

SUCCESS PATTERN NO.

[SUCCESS PROB VECTOR] BEFORE 1ST PASS = $\begin{array}{cccc} 0 & 1 & 2 & 31 \\ [1, & 0, & 0 & \ldots 0] \end{array}$

MATRIX MULTIPLICATION FOR EACH PASS

SUCCESS PROB VECTOR AFTER EACH PASS

ORBITS

TARGET AREA LATITUDE

MISSION DURATION

MAXIMUM OBLIQUITY

TIME OF YEAR (FOR 57° ORBITS)

NUMBER OF ACCESS OPPORTUNITIES DURING MISSION

PROBABILITIES OF EXCEEDING CLOUD FREE THRESHOLDS

The next three charts summarize some of the weather data provided by the Air Weather Service. This chart displays the variation of clearness probabilities with threshold level (% cloud-free) in dense target areas at two latitudes, 25° and 50°. During spring and summer months, the probability of exceeding 60% cloud-free in the southern China area is 0.1 or below. To obtain imagery in such conditions, an appropriate operational procedure might lower the threshold to perhaps 40%. More film would be wasted but the likelihood of missing opportunities due to prediction errors would be reduced.

For the analysis in this study, it is assumed that, even when targeting is done at lower thresholds, only those images taken when the sky was 60% or more cloud-free contribute to meeting requirements. However, only one such image, taken in a given target cell (50 nm wide), is assumed to be needed to meet the 80% take requirement. The validity of this assumption is supported not only by the fact that for a 60% threshold (of "verified" weather) the expected full-sky clearness is generally near 80% but that the percentage of cloud free imagery ("confirmed" results) averages still higher, in the vicinity of 90%. Data on this point is provided in Appendix D.

The majority of analysis was based on the two cases in solid boxes, March in southern China and November in western USSR, where the "single point" probability of exceeding 60% cloud free weather is approximately 0.1. This value is "typical" for much of the year in southern China and essentially worst-case for the selected area in western USSR. The points in dotted boxes were also evaluated to determine effects under favorable weather conditions.

PROBABILITIES OF EXCEEDING CLOUD FREE THRESHOLDS

25°N, 110°E – SOUTHERN CHINA

THRESHOLD

MO.	40%	60%	80%
1	.245	.201	.162
2	.203	.157	.097
3	.135	.104	.080
4	.136	.093	.053
5	.086	.028	.003
6	.137	.066	.024
7	.149	.038	.001
8	.219	.112	.017
9	.338	.159	.012
10	.339	.224	.117
11	.380	.287	.198
12	.409	.365	.321
MEAN		.154	
ST DEV		.101	

0.1 IS 0.5σ BELOW MEAN

50.5°N, 40.5°E – WESTERN USSR

MO.	40%	60%	80%
1	.445	.367	.288
2	.330	.228	.145
3	.426	.342	.264
4	.393	.287	.204
5	.538	.379	.217
6	.551	.362	.206
7	.535	.380	.241
8	.583	.439	.280
9	.497	.363	.243
10	.362	.269	.169
11	.160	.101	.061
12	.170	.097	.053
		.301	
		.110	

0.1 IS 1.8σ BELOW MEAN

PROBABILITIES OF 60% CLOUD FREE FOR VARIOUS STRIP WIDTHS

The magnitude of spatial correlation of clearness in cloud patterns is shown here by the decrease in clearness probabilities as wider strips are considered. For "fully correlated" weather, the probabilities for 150 and 250 nm strips would be the same as for a 50 nm strip (data for single grid point), and the ratios (P/P_{50}) would be unity. Thus strong correlation involves high values of P/P_{50} and weak correlation is indicated by low P/P_{50}.

It is seen that, even though March in southern China has nearly the same single-point probability as November in western USSR, the spatial correlation is strong (about 1 sigma high) in the former case and near minimum (about 1.7 sigma low) in the latter.

PROBABILITIES OF ≥60% CLOUD FREE OVER VARIOUS STRIP WIDTHS

25°N, 110°E – SOUTHERN CHINA					
STRIP WIDTH (NM)	50	150		250	
MONTH	P_{50}	P	P/P_{50}	P_{250}	P/P_{50}
1	.201	.165	.821	.134	.667
2	.157	.106	.675	.077	.490
3	.104	.090	.865	.065	.625
4	.093	.068	.731	.044	.473
5	.028	.009	.321	.000	.0
6	.066	.041	.621	.022	.333
7	.048	.023	.479	.008	.167
8	.112	.058	.518	.022	.196
9	.159	.082	.516	.022	.138
10	.224	.138	.616	.078	.348
11	.287	.232	.808	.181	.631
12	.365	.331	.907	.307	.841
MEAN			.656		.409
STD DEV			.178		.254
		$\bar{x}+\sigma =$	.834		.663

MAR. HAS 0.1 PROB WITH <u>STRONG</u> SPACIAL CORRELATION

50.5°N, 40.5°E – WESTERN USSR					
	50	150		250	
MONTH	P_{50}	P	P/P_{50}	P_{250}	P/P_{50}
1	.367	.289	.787	.239	.651
2	.228	.147	.645	.098	.430
3	.342	.254	.743	.212	.620
4	.287	.205	.714	.150	.523
5	.379	.242	.639	.161	.425
6	.362	.240	.663	.172	.475
7	.380	.265	.697	.204	.537
8	.439	.309	.704	.215	.490
9	.363	.242	.667	.169	.466
10	.224	.138	.616	.078	.348
11	.101	.056	.554	.028	.277
12	.097	.053	.546	.032	.330
MEAN			.668		.470
STD DEV			.070		.107
		$\bar{x}-\sigma =$	.598		.363

NOV. HAS 0.1 PROB WITH <u>WEAK</u> SPACIAL CORRELATION

FREQUENCY DISTRIBUTION OF WEATHER PATTERNS

This chart displays some of the data provided by the Air Weather Service in the form used for input to the analysis. Each value listed represents the probability of the sky being 60% or more cloud free in a specified pattern over a 250 nm wide strip (as estimated by the frequencies experienced in a given month, averaged over the four year period from 1972 through 1975).

To improve the statistics, data was taken from 15 grid points each day in a format of 5 points east-west and 3 north-south. Thus the number of data points for which data was apportioned to the 32 patterns was typically 360 (30 days x 4 years x 3 rows). Many of the possible patterns never occurred (giving zero) and the smallest value (0.0027 or 0.0028, representing one case out of the 360 or so) occurred for several patterns. The higher probabilities other than the 00000 case, generally represent continuous strips of relatively clear sky.

FREQUENCY DISTRIBUTIONS OF WEATHER PATTERNS

FIVE 50 NM GRID POINTS IN 250 NM EAST-WEST STRIP
0 MEANS <60% CLOUD FREE, 1 MEANS ≥60% CLOUD FREE

SOUTHERN CHINA (25°N, 110°E)

		MAR (P_L = .104)		NOV (P_L = .287)	
WESTERN GRID POINT		0	1	0	1
BINARY VALUES	OTHER FOUR GRID PTS.				
0,16	0000	.8683	.0000	.6000	.0389
1,17	0001	.0134	.0000	.0139	.0000
1,18	0010	.0000	.0000	.0000	.0056
3,19	0011	.0000	.0027	.0139	.0000
4,20	0100	.0027	.0000	.0083	.0000
5,21	0101	.0000	.0000	.0000	.0000
6,22	0110	.0000	.0000	.0056	.0000
7,23	0111	.0054	.0000	.0222	.0000
8,24	1000	.000	.0027	.0056	.0222
9,25	1001	.0000	.0000	.0000	.0000
10,26	1010	.0000	.0000	.0000	.0000
11,27	1011	.0000	.0000	.0000	.0000
12,28	1100	.0000	.0027	.0056	.0194
13,29	1101	.0027	.0000	.0000	.0028
14,30	1110	.0027	.0242	.0000	.0389
15,31	1111	.0081	.0645	.0167	.1806

WESTERN USSR (50.5°N, 40.5°E)

	NOV (P_L= .101)		MAY (P_L = .379)	
W. GR. PT	0	1	0	1
OTHER FOUR GRID POINTS				
0000	.8000	.0139	.3861	.0389
0001	.0306	.0000	.0556	.0139
0010	.0139	.0028	.0056	.0028
0010	.0222	.0028	.0611	.0028
0100	.0139	.0000	.0056	.0000
0101	.0000	.0000	.0028	.0000
0110	.0028	.0028	.0000	.0000
0111	.0056	.0000	.0694	.0028
1000	.0028	.0000	.0056	.0361
1001	.0000	.0000	.0028	.0083
1010	.0000	.0038	.0000	.0000
1011	.0028	.0000	.0000	.0111
1100	.0056	.0111	.0139	.0306
1101	.0000	.0000	.0028	.0139
1110	.0056	.0167	.0083	.0333
1111	.0139	.0278	.0250	.1611

BASED ON 4 YR. AVERAGE (1972 THRU 1975), 15 GRID POINTS (3x5), 3D-NEPH DATA

RANGE OF SPATIAL CORRELATION EFFECTS

The level of spatial correlation has significant effect on quantity performance as seen here by comparing $P(\geq 1)$ for two cases with essentially the same value of "problook" but different correlation. Also shown, by the dotted lines, is the low sensitivity to the target strip width, as calculated in the preliminary analysis, using an intermediate level of correlation. These results support use of 250 nm for strip width for the remainder of the study.

The upper curve is computed using the simple formula:

$$P(\geq 1) = 1 - (1 - P_L)^N$$

where

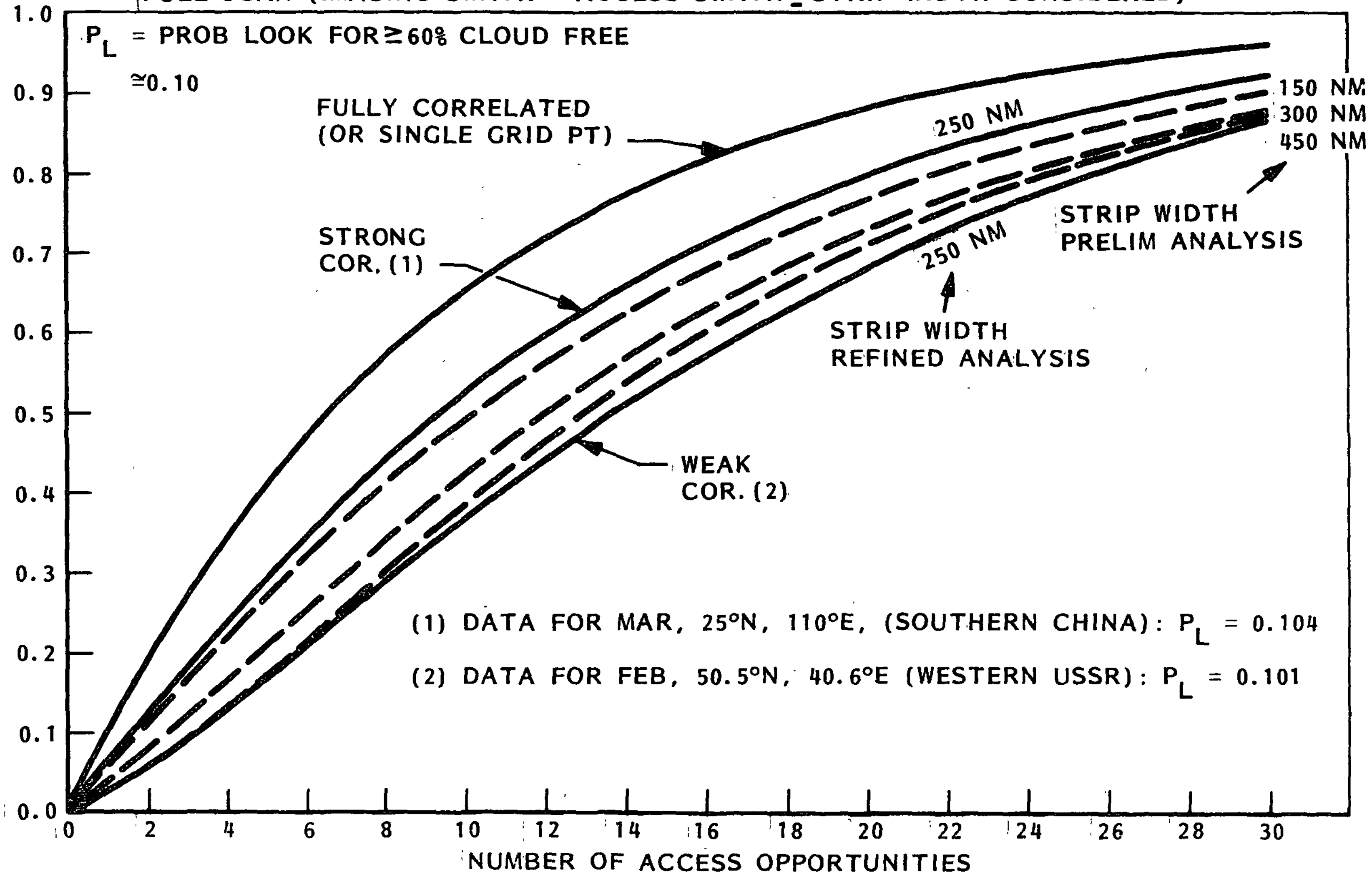
P_L = Probability of 60% cloud free weather for a random grid point (Problook)

N = Number of access opportunities

The other solid curves result from the 32 x 32 matrix multiplication in the refined analysis with no image swath screening. The dotted curves provide approximate results obtained from an 8 x 8 matrix multiplication derived from a 3 cell wide target strip with different cell widths.

RANGE OF SPATIAL CORRELATION EFFECTS

FULL SCAN (IMAGING SWATH = ACCESS SWATH ≥ STRIP WIDTH CONSIDERED)



(1) DATA FOR MAR, 25°N, 110°E, (SOUTHERN CHINA): $P_L = 0.104$

(2) DATA FOR FEB, 50.5°N, 40.6°E (WESTERN USSR): $P_L = 0.101$

MAXIMUM EFFECT OF PARTIAL ACCESS TO 250 NM STRIP ON SOME PASSES

The purpose of this chart is to confirm the reasonableness of another assumption made throughout the remainder of the analysis. Specifically, it shows the results are only slightly affected by assuming repeated central passes over the 250 nm strip on each successive access opportunity. When S/T is unity (minimal day-to-day closure) on a near polar orbit, there are typically two accesses each repeat cycle. However, these two accesses to a strip of width T (day-to-day track spacing) accumulate typically in three passes, one in the middle of the strip and one at each end; this is referred to here as the C-R-L pattern of access.

The two lower curves on each chart show, then, that the analysis predicts a small penalty in overall quantity of take in an isolated 250 nm strip for the C-R-L access pattern. Since, however, the 250 nm strip is generally not isolated but is only a representative strip in a wider overall target region, the full access curves may, in fact, be considered better predictors of overall performance than the C-R-L curves. In any case, the effect is quite small.

MAXIMUM EFFECTS OF PARTIAL ACCESS TO 250 NM STRIP ON SOME PASSES

S/T = ACCESS SWATH – DAILY TRACK SPACING = 1

IMAGING SWATH = ACCESS SWATH

C-R-L ACCESS PATTERNS FOR EACH REPEAT CYCLE:
(2 ACCESSES PER REPEAT CYCLE)

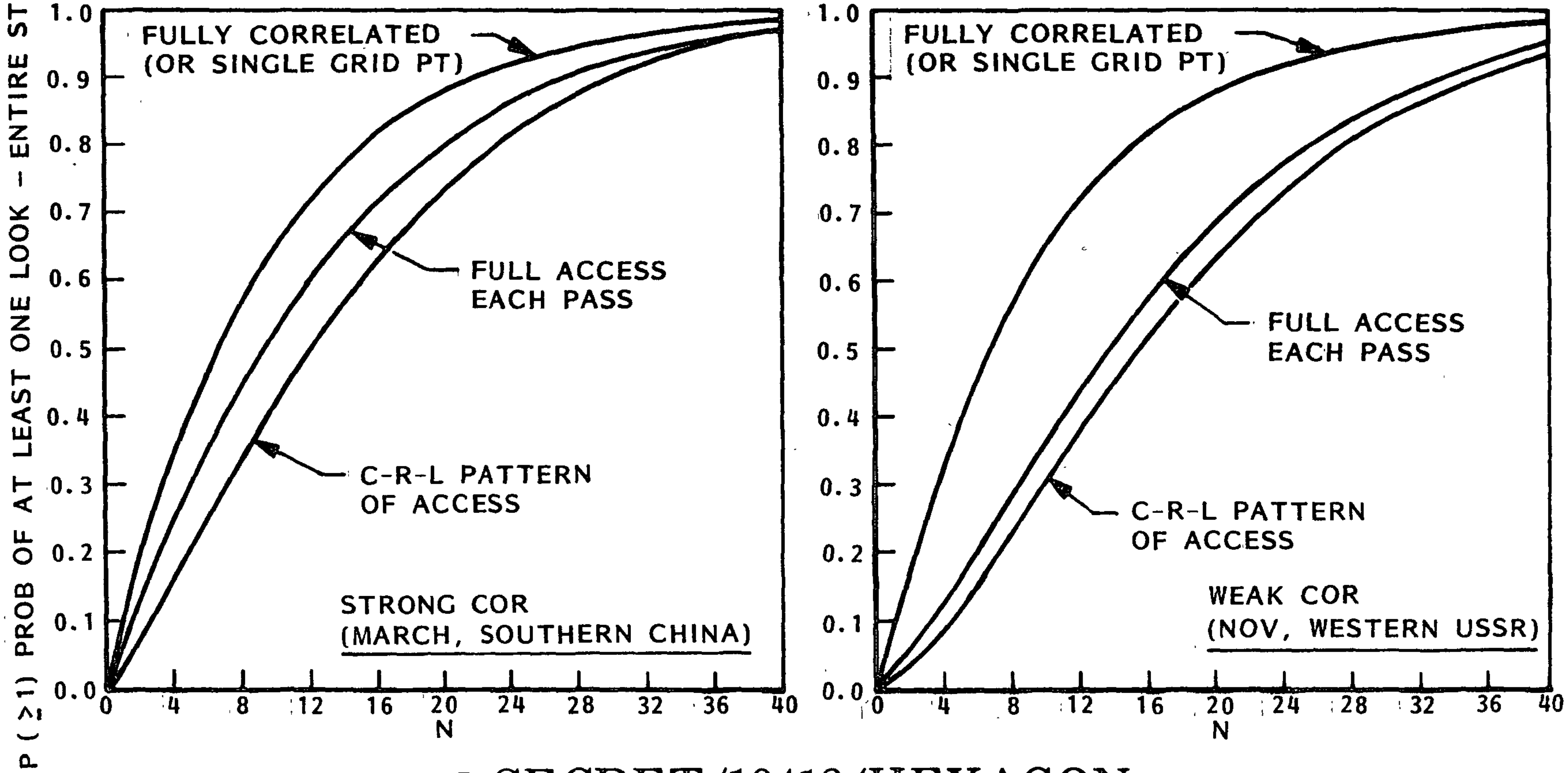
PROB LOOK (>60% CLOUD FREE) = 0.10

◄ 250 NM ►

▨▨▨▨ C (CENTER PASS) – PASS 1

□□▨▨ R (RIGHT-EDGE) – PASS 2

▨▨□□ L (LEFT-EDGE) – PASS 3



EFFECTS OF IMAGING SWATH - POOR WEATHER MONTHS

These curves show the surprisingly severe effect on P(≥1) when the imaging swath is less than the access swath, or more specifically if it is less than the target strip width of 250 nm. If the access swath and imaging swath are equal and 250 nm or more, then the curve labeled 250 applies. (For access swaths greater than 250 nm, the increase in performance is reflected in increased access opportunities which is proportional to S/T.) Labels on the curves of less than 250 indicate a choice of imaging on each access with the stated width anywhere within the 250 nm strip; e.g., 100, 150 and 200 correspond to 2, 3, and 4 50 nm weather cells respectively.

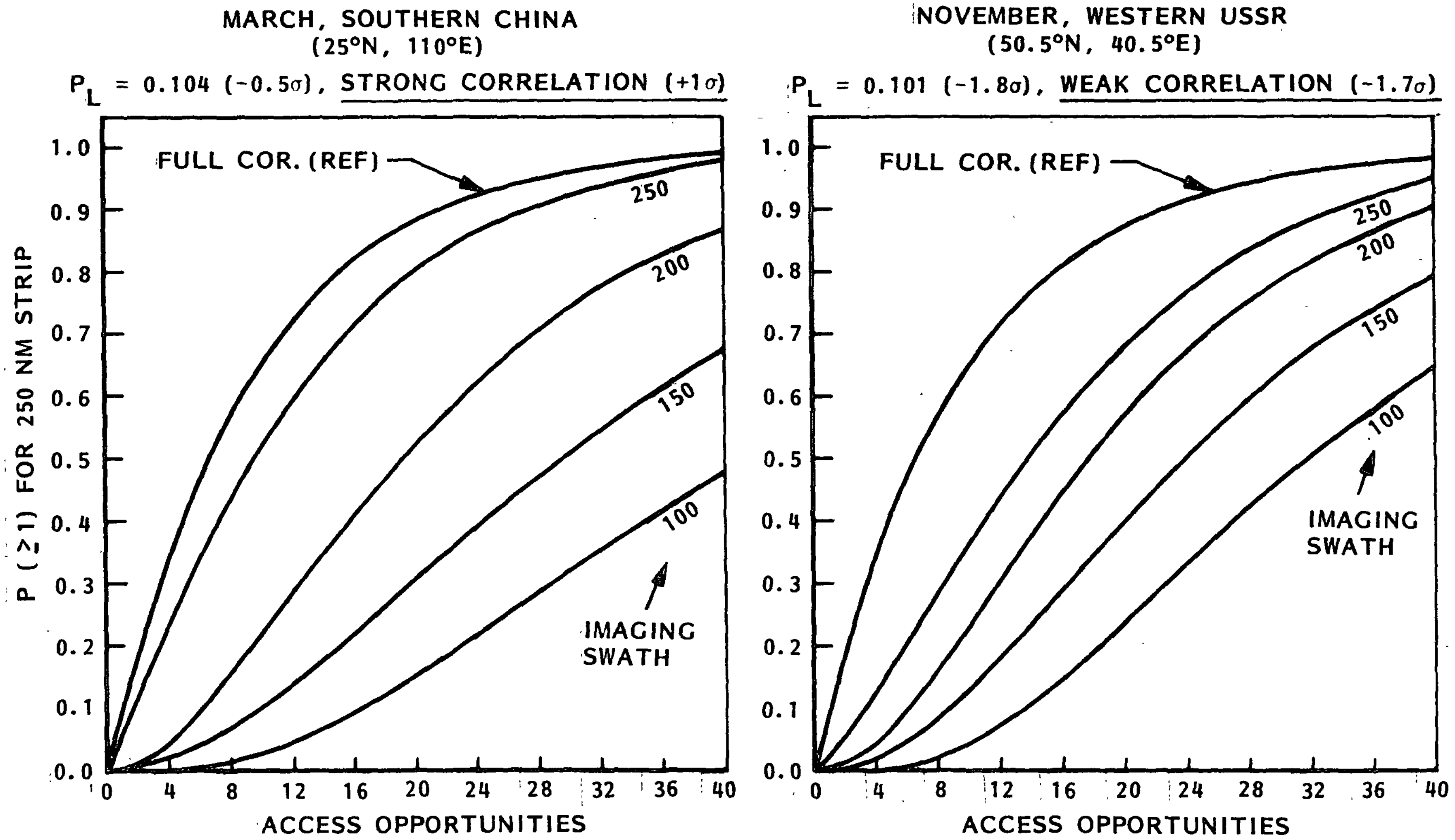
To understand the severity of this effect, notice that the initial slope is zero. This is due to the fact that it will take more than one access to obtain a non-zero value of P(≥1). Thereafter, the accumulating probability is degraded by two effects: (1) on each successful access only a portion of the 250 nm strip can be imaged, leaving the remainder for later opportunities, and (2) the probabilities for each portion must be combined (by multiplication since probabilities on successive passes are assumed independent) resulting in a further decrease in the probability of imaging in all five cells.

For instance, assuming full correlation and an imaging swath one half as wide as the target strip (125 nm), one would expect to require twice as many opportunities to image each 125 nm area as for full width imaging (when imaging one, the other is neglected). Then the resulting probability for each must be multiplied to obtain P(≥1), the probability of looking at both 125 nm areas. The effect predicted for actual weather conditions by the screened matrix analysis used here is even more severe. This results from the less than full spatial correlation implicit in the probabilities for the 32 possible weather patterns.

It has been concluded that the benefit in performance of an SCS system with full scan capability (approximately ±40°) is sufficient to justify the more complex camera, both for pallets and free-flyers. In both cases the camera pointing problem is less severe. It allows for instance, the possibility of using momentum wheels rather than the more complex CMGs in the free-flyer application, since high-rate attitude changes are not required for the full-scan case.

EFFECTS OF IMAGING SWATH—POOR WEATHER MONTHS

PROBABILITY OF AT LEAST ONE LOOK (≥60% CLOUD FREE) AT ALL PORTIONS OF 250 NM STRIP



MARCH, SOUTHERN CHINA
(25°N, 110°E)
P_L = 0.104 (-0.5σ), STRONG CORRELATION (+1σ)

NOVEMBER, WESTERN USSR
(50.5°N, 40.5°E)
P_L = 0.101 (-1.8σ), WEAK CORRELATION (-1.7σ)

QUANTITY PERFORMANCE IN POOR WEATHER

The number of access opportunities, as presented in Section 4, Operational Considerations, has been used to enter curves of P(≥1) (see previous two charts for curves applicable to P(≥60%) = 0.10) to compute quantity performance for four systems under relatively poor weather conditions. Adequate performance at the weather levels chosen are considered a reasonable basis for design criteria.

Dividing P(≥1) for the three study systems by the hexagon value under the same conditions yields a parameter whose absolute value is of increased significance. It can be seen that the 20 day ETR Pallet performance approaches that of 60 days of hexagon operations, while the WTR Pallet performs only 25% to 50% as well as hexagon at the most important latitudes.

Two SCS free-flyers (with ±40° scan capability) at 170 nm, for NIIRS-4 imagery, can provide adequate quantities of cloud-free imagery even in poor weather. Dropping one free-flyer to 130 nm for 60 days could give more good imagery than 60 days of hexagon, the higher altitude more than compensating for the decrease in scan angle from ±45° to ±40°.

QUANTITY PERFORMANCE IN POOR WEATHER

PROBABILITY OF AT LEAST ONE LOOK – P(≥1), ALL PORTIONS OF 250 NM STRIP

	P(≥1)				P(≥1) ÷ HEXAGON P(≥1)				
LATITUDE	0°	25°	50°	60°	0	25°	50°	60°	
P(≥60%) – EA OPPTY	0.287	0.10	0.10	0.10	0.287	0.10	0.10	0.10	AVE
SPATIAL CORRELATION	STRONG	STRONG	WEAK	WEAK	STRONG	STRONG	WEAK	WEAK	
ETR PALLET									
±40° ACCESS WINT SOL	0.62	(2)	0.52	0.0	0.70		1.08	0.0	0.89
20 DAYS EQUINOX	0.62	0.39	(2)	0.0	0.70	0.78		0.0	0.74
SUM SOL	0.62	0.45	(2)	0.0	0.70	0.90		0.0	0.80
WTR PALLET									
±40° ACCESS 18 DAYS	0.55	0.23	0.18	0.28	0.62	0.26	0.38	0.46	0.43
FREE-FLYERS (WTR)									
±40° ACCESS 170 NM, 2 SATS 60 DAYS	0.98	0.91	0.95	0.97	1.10	1.82	1.98	1.59	1.62
130 NM, 1 SAT	0.92	0.56	0.57	0.70	1.03	1.12	1.19	1.15	1.12
HEXAGON (REF) ±45° ACCESS 60 DAYS	0.89	0.50	0.48	0.61					

NOTES: (1) BASED ON "WORST CASE" WEATHER AT EACH LATITUDE.
(2) 0.10 WEATHER NOT APPLICABLE TO THIS SEASON.

PROBABILITIES OF ≥60% CLOUD FREE IN FOUR TARGET AREAS

Data for the two areas on the left were previously presented. Data for the two on the right were obtained later from AF/AWS to provide a wider base for investigation of system performance in moderate (representative) weather conditions.

The four sets of values in boxes designate cases chosen for further study. Two cases represent moderately poor weather (0.155 to 0.157) but with differing levels of spatial correlation. The other two cases are medium weather (0.226 and 0.239) with about the same range of correlation.

It is interesting to compare weather for the three areas in the western target region. It is generally poorer but more uniform (throughout the year) in the chosen European area (which is near Prague) than in the western USSR area at the same latitude. Moscow weather is similar to (but poorer) through the year to the western USSR area (about 300 mi to the south). It appears that weather as poor as the 0.10 level is quite rare in this overall region, but that values in the range from 0.13 to 0.25 are quite common.

PROBABILITY OF ≥ 60% CLOUD FREE AT FOUR POINTS

MONTH	25°N, 110°E S. CHINA		50.5°N, 40.5°E W. USSR	50°N, 15°E EUROPE		55.7°N, 37.6°E MOSCOW	
	P	P(250)/P	P	P	P(250)/P	P	P(250)/P
1	0.201		0.367	0.125		0.321	
2	0.157	0.490	0.228	0.156		0.239	0.486
3	0.104		0.342	0.183		0.311	
4	0.093		0.287	0.132		0.226	0.344
5	0.028		0.379	0.153		0.270	
6	0.066		0.362	0.141		0.273	
7	0.048		0.380	0.155	0.303	0.266	
8	0.112		0.439	0.303		0.245	
9	0.159		0.363	0.240		0.229	
10	0.224		0.269	0.168		0.141	
11	0.287		0.101	0.118		0.086	
12	0.365		0.097	0.178		0.084	
$\overline{X}$	0.154		0.301	0.101		0.224	
S*	0.101		0.110	0.053		0.079	
P = 0.10 IS	-0.53σ		-1.82σ	-1.34σ		-1.57σ	

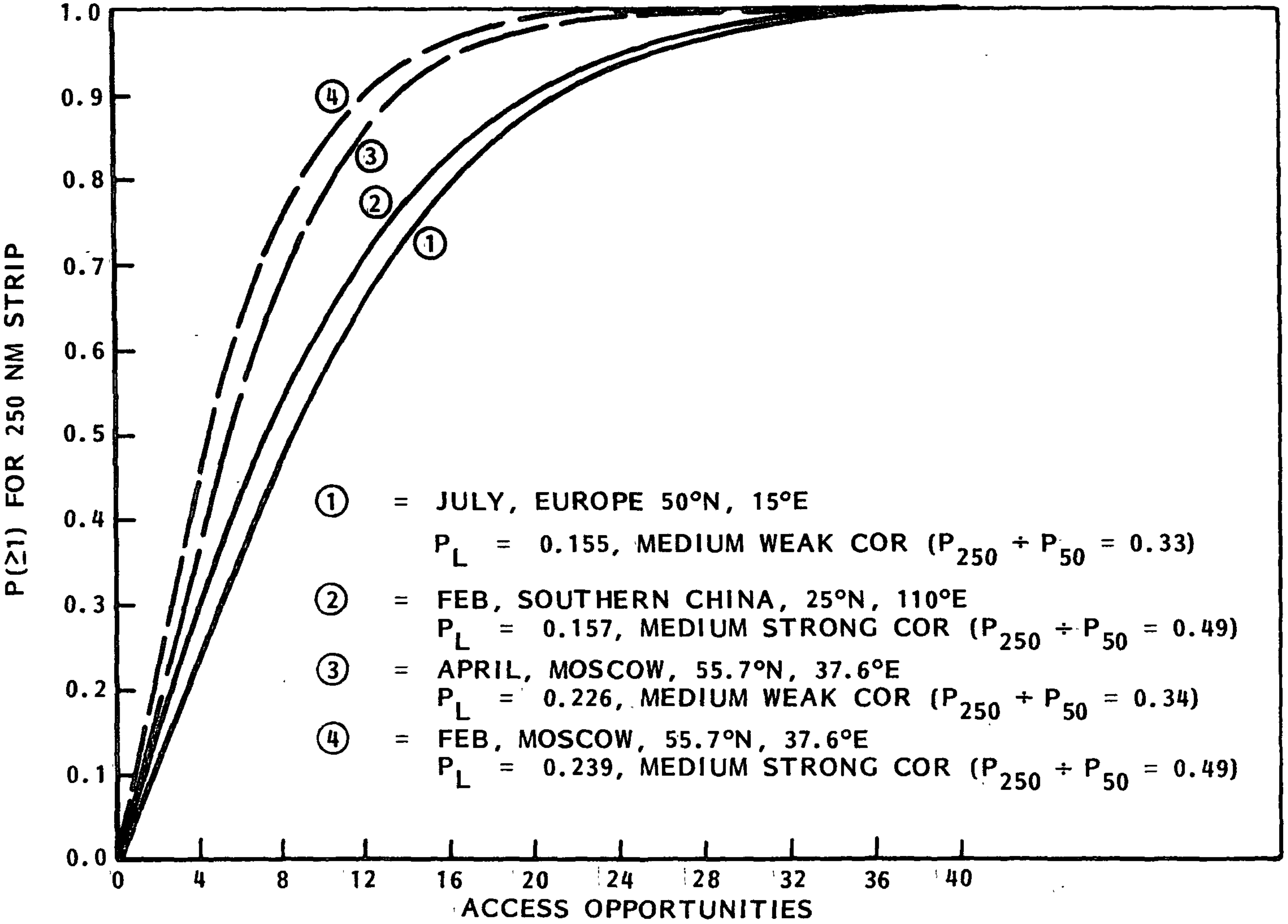
*STANDARD DEVIATION.

PROBABILITY OF AT LEAST ONE LOOK
(TYPICAL MODERATE WEATHER)

These curves show the values of P(≥1) for the four cases identified on the previous chart. They were used to compute system performance for several of the cases on the next chart.

It is noteworthy that the range of correlation considered here (1/3 to 1/2 for P_{250}/P_{50}) resulted in only minor impact on P(≥1). This is so even though a large effect of correlation was noted in the earlier analysis for poor weather cases. There is a greater decrease in this sensitivity than would be expected by the decrease in range of correlation, as measured by P_{250}/P_{50} (the moderate weather cases have about 45% of the range in this parameter as the previous poor weather cases). While the reason for this shift in sensitivity is not clear, it appears that, as correlation decreases, there is a sharp rise in the impact on P(≥1) below a value of about 0.3 for P_{250}/P_{50} and/or a significant increase in sensitivity to correlation as problook drops from about 0.15 to 0.10.

PROBABILITY OF AT LEAST ONE LOOK— TYPICAL MODERATE WEATHER



QUANTITY PERFORMANCE IN REPRESENTATIVE WEATHER BY SEASON

Typical performance for four systems is presented. It is based on P(≥1) curves for weather representative of 25° and 50° latitude dense target areas in each of the four seasons. The weather levels chosen were representative, i.e., in terms of P(≥60%) for a random cell (problook) and the correlation level (as measured by P_{250}/P_{50}). The location from which the data were derived does not always correspond to the location at which it was applied, but the weather quality was chosen to be representative.

It can be seen that the 20 day 57° (ETR) pallet performance always exceeds 60 day hexagon performance at 50° latitude and is not seriously worse at 25°. Averaging the two cases (latitudes), as on the right, shows performance throughout the year which approximates that of 60 days of hexagon operations – more nearly so than for the poor weather results presented earlier.

The average performance for the (WTR) 97° pallet in representative weather is somewhat better than that in poor weather ($P/P_H = 0.43$) but not very encouraging. The 97° free-flyer system, on the other hand, shows good results for both the representative weather and the poor weather cases.

QUANTITY PERFORMANCE IN REPRESENTATIVE WEATHER BY SEASON

DENSE TARGET AREAS AT 25° CHINA AND 50° EUROPE LATITUDE

	P(≥1)								AVERAGE VALUE OF P(≥1) ÷ HEXAGON P(≥1) FOR 25° AND 50° LAT			
	WINTER D, J, F		SPRING M, A, M		SUMMER J, J, A		FALL S, O, N					
LATITUDE	25°	50°	25°	50°	25°	50°	25°	50°	WINTER	SPRING	SUMMER	FALL
PROBLOOK	0.287	0.155	0.104	0.226	0.101	0.239	0.155	0.239				
SPATIAL CORRELATION	STRONG	MEDIUM WEAK	STRONG	MEDIUM WEAK	WEAK	MEDIUM STRONG	MEDIUM WEAK	MEDIUM STRONG				
ETR PALLET ±40° ACCESS, 20 DAYS	0.74	0.74	0.39	0.98	0.29	0.99	0.41	0.99	1.08	0.94	0.96	0.92
WTR PALLET ±40° ACCESS, 18 DAYS	0.58	0.32	0.24	0.53	0.13	0.58	0.23	0.58	0.61	0.54	0.51	0.53
FREE-FLYERS (WTR) ±40° ACCESS, 60 DAYS												
170 NM, 2 SATS	0.99	0.99	0.91	0.99	0.84	0.99	0.97	0.99	1.45	1.47	1.77	1.44
130 NM, 1 SAT	0.93	0.78	0.57	0.94	0.56	0.96	0.62	0.96	1.23	1.10	1.35	1.1[illegible]
HEXAGON (REF) ±45° ACCESS, 60 DAYS	0.90	0.55	0.50	0.89	0.34	0.92	0.54	0.92				

TYPICAL PATTERNS OF POOR WEATHER

Actual weather patterns reported in the 3D-NEPH* input tapes for five East-West cells in the first 25 days of December (1972 through 1974) are displayed. The values shown are percent cloud free (full sky, noon weather) of each day on which at least one cell was 40% or more cloud free. On days shown blank, the percent cloud free was less than 40% for all five cells.

The general nature of both spatial correlation and temporal correlation effects is noticeable. The former was taken into account in the results presented so far. The latter was not, in that it was assumed that success on each day's opportunity is independent of that for other days. This assumption is partially justified by the fact that successive opportunities generally occur 3 or 4 days apart. For analysis of poor weather cases, such as shown here, this assumption seems quite valid since good weather periods are short lived. It may be less justified in cases of better weather and actual performance of all systems should be somewhat better than has been estimated.

Another aspect of temporal correlation effects in poor weather is that there can be long periods with no access opporunities. The effect of temporal correlation on short 20 day (pallet) missions, is more severe than for longer missions. While measures of central tendency, such as expected return or probability of at least one look, P(≥1), are not affected by this consideration, the distribution of success from mission to mission will be more widely spread for short missions than for longer ones. The magnitude of this effect is being analyzed statistically and results will be reported later in an appendix under separate cover.

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*3D-NEPH is the title of the 3-dimensional historical cloud-data catalog currently in use by the Air Weather Service (nepho- is prefix meaning clouds).

TYPICAL PATTERNS OF POOR WEATHER

DECEMBER, 50.5°N LAT, 40.5°E LONG, WESTERN USSR (P ($\geq$ 40) = .170, P ($\geq$ 60) = .097)

	% CLOUD FREE																			
	1972					1973					1974					1975				
DECEMBER DATE	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
1	5	15	30	40	85															
2	25	55	75	85	45	15	40	60	55	40										
3						30	25	50	80	75	50	65	65	60	35					
4	55	20	15	5	0											0	0	0	20	70
5																				
6																				
7						40	30	20	30	25										
8																50	75	55	25	65
9																				
10																				
11						95	95	85	80	85										
12						100	95	75	45	20										
13						20	20	40	25	5	75	60	65	90	80	25	10	30	75	90
14						30	45	50	70	45										
15											90	100	100	100	50	70	40	25	15	20
16											100	100	100	60	70					
17											50	60	55	25	0	65	85	95	100	100
18	50	55	40	20	15															
19	5	10	30	45	30															
20	10	15	10	25	40	90	100	90	80	90						90	85	50	30	20
21																70	50	25	15	5
22																45	50	20	25	55
23																20	10	40	65	55
24																60	40	45	40	10
25																				

NOTES: % CLOUD FREE DATA SHOWN FOR ALL GRID POINTS ON DAYS FOR WHICH AT LEAST ONE GRID WAS 40% OR MORE,

☐ = 60% OR MORE, X = 40% OR MORE

PERFORMANCE ANALYSIS - SUMMARY

The major conclusions from the analysis of quality and quantity performance of pallets and free-flyers are summarized here. In both cases, it has been concluded that the camera design should provide about ±40° scan and that aperture should be increased somewhat to allow operation at higher altitudes. Typically, an aperture increase of about 13% would maintain NIIRS-4 quality at 170 nm (i.e., 170/150 = 1.13).

An increase of similar magnitude is appropriate for the 57° (ETR) pallet case, even though it operates at 150 nm altitude. In this case the increase is to compensate for lower average sun angles, and to obtain some NIIRS-5 imagery under most favorable conditions. While the optimum F number would be somewhat lower for the 150 nm (pallet) case than for the 170 nm (free-flyer), performance of the latter is not very sensitive to F number (as shown by the 40° sun angle analysis in the SCS report by EK). A compromise focal length could be chosen as a basis for an SCS camera design applicable to either 57° (ETR) pallet or a 97° (WTR) free-flyer.

PERFORMANCE ANALYSIS—SUMMARY

PALLETS

ETR PALLET AT 57° INCLINATION IS ATTRACTIVE

- SCAN CAPABILITY SHOULD BE ±40° OR MORE
- 20-DAY CAPABILITY NEAR HEXAGON 60-DAY CAPABILITY
- EXCELLENT COVERAGE FROM 45° TO 58° LATITUDE

WTR PALLET SHOWS LIMITED CAPABILITY

SUN SYNCHRONOUS FREE FLYERS WITH ±40° SCAN

TWO (2) SATELLITES IN 170 NM CIRCULAR ORBIT ARE ADEQUATE TO MEET NIIRS-4 REQUIREMENTS

- GOOD REPEAT CYCLE
  (Q = 15 13/15, 2 SATS → 4 ACCESSES EVERYWHERE EACH 15 DAYS)
- APPROXIMATELY 60% BETTER COVERAGE THAN HEXAGON
- SCS APERTURE SHOULD BE INCREASED ABOUT 13° (170/150) TO MEET NIIRS-4 REQUIREMENTS

DROPPING ONE SATELLITE TO 130 NM MEETS NIIRS-5 REQUIREMENTS

- 60 DAY OPERATION (AS NEEDED) IS ADEQUATE DURATION
- GOOD REPEAT CYCLE: Q = 16 2/15 → 2 ACCESS EACH 15 DAYS

6 OPERATIONAL CONCEPTS

OPERATIONAL CONCEPTS

A key concern for both pallet and free-flyer operational concepts which has a major cost impact is the availability of shared shuttle opportunities. SCS pallets could share rides with 63.4° inclination missions whose satellites are deployed from the shuttle and subsequently boosted to higher orbits. These missions would initially be launched from ETR into a 57° inclined orbit. At a later time (post 1984) such missions could be launched from WTR directly into a 63.4° inclination. This approach would preclude the inclination change (57 to 63.5°) as part of the transfer to higher orbit. However, NASA documentation indicates possible External Tank (ET) disposal problems at 63.4° from WTR. Shuttle pallets were evaluated and look attractive in the 57°/ETR launch; and the 63.4° inclination should be even more attractive, since the maximum latitude for coverage would be about 65° as compared to 59°.

Available data indicates that the principal ET disposal problems are political, involving international agreements on re-entry of debris below 60° south latitude, approaching Antarctica. Action by the United States to obtain waivers could be initiated if the advantages to be gained provide adequate justification. The potential use of 63.4° pallets on shared rides with 63.4° deployables could add significantly to justification for initiating such action.

This section includes a preliminary estimate of the available ride-sharing opportunities plus pallet and free-fly operational considerations.

ESTIMATED RIDE-SHARING OPPORTUNITIES

NASA planning on ride-sharing (for NASA flights only) has been done in fair detail but is based on very preliminary mission data beyond 1982. Nearly all the available capability has been allocated to multiple use. As plans firm up and new missions are added (such as the SCS), flight loading will be reallocated to new mixes. Little data on planning for ride-sharing of DOD missions have yet been published and the data here are based on individual mission plans.

The sharing of an SCS pallet with "deployable only" flights would be desirable since on-orbit compatibility problems are reduced. All DOD flights shown are deployable and these are separately totaled with NASA deployables (which are all currently planned in multiple missions).

Based on current planning, the total number of high inclination ETR-launched flights decreases after 1984, while those at WTR show a rapid increase. After 1984, NASA plans to shift all high inclination operations to WTR. The remaining shuttle flights are all DOD and those are for deployment of 63.4° satellites which could also shift to WTR if ET disposal problems are solved. A factor which could shift some NASA pallet flights back to ETR is the recent decrease in shuttle payload capability projections, which could force use of compromise inclinations for some of NASA's earth viewing pallet missions.

While the number of flights indicated shows more opportunities beyond 1984 from WTR than ETR, long life free-flyers (more suitable for WTR operations) are more critical to inclination than are short-lived pallets and may not be compatible with many of the indicated flights.

ESTIMATED RIDE-SHARING OPPORTUNITIES

	ETR (≥50° INCL)					WTR				
	82	83	84	85	86	82	83	84	85	86
POTENTIAL RIDE-SHIRING OPPORTUNITIES										
• DEPLOYABLES ONLY (AS NOW PLANNED)										
NASA							2	1		3
DOD	1	2	3	2	4		2	4	5	4
TOTAL	1	2	3	2	4		4	5	5	7
• MIX OF NASA DEPLOYABLE AND PALLET PAYLOADS								1	4	
• NASA PALLET ONLY MISSIONS	3	2	2					2		
TOTAL POTENTIAL NASA	3	2	2				2	4	4	3
SHARING OPPORTUNITIES DOD	1	2	3	2	4		2	4	5	4
TOTAL	4	4	5	2	4		4	8	9	7

NOTES: (1) ONLY 1 TO 3 NASA FLTS/YR NOW SHOW SUFFICIENT AVAILABLE SPACE/WEIGHT (DUE TO SHARING ALREADY PLANNED)

(2) NASA OPPORTUNITIES INCLUDE:
- DEPLOYABLES ARE ALL MIXES OF 2 OR MORE PAYLOADS (AS NOW PLANNED)
- NO FLIGHTS WITH FOREIGN SCIENCE
- NO SPACELAB MODULE FLIGHTS (RETURN PAYLOAD LIMITED)

(3) DOD OPPORTUNITIES INCLUDE:
- ETR: 3 PROGRAMS TO BE BOOSTED TO 12 HR, 63.4 DEG INCLINATION
- WTR: BASED ON NASA TRAFFIC MODEL WITH ADJUSTMENTS BASED ON DOD PROGRAM DATA

PALLET CONCEPT

ETR pallet operations at 57° inclination are an attractive approach. Three to four operations per year would provide significant contribution to meeting the wide area search requirements. The limitation of the ETR pallets are: (1) low frequency of return and (2) inability to obtain targets above 59° lattitude.

The SCS camera designs need to be reconfigured somewhat for 57° (pallet) operations. In addition to the needed increased scan to ±40°, the aperture should be increased (approximately 10-20%) and the camera designs should address the lower average sun angles resulting from the 57° inclined orbits. This factor will drive the camera designs to faster systems (lower F-no ~3.0 to 3.5) to reduce the exposure time to minimize the smear effect on resolution.

PALLET CONCEPT

ETR OPERATIONS (TYPICAL)

- 20 DAY ORBIT LIFE
- 159 NM CIRCULAR ORBIT AT 57° INCLINATION
- 5000 LB WITH INCREASED CAMERA SCAN TO ±40°

PERFORMANCE SUMMARY (3-4 OPERATIONS/YR)

- QUALITY – CAMERA DESIGNS (INCREASE APERTURE FOR FASTER SYSTEM) WILL PROVIDE NIIRS-4
- QUANTITY – WILL SATISFY MAJORITY OF REQUIREMENTS; EXCEPT TWO MONTH REQUIREMENT AND TARGETS ABOVE 59° LATITUDE

PALLET SYSTEM - OPERATIONAL CYCLING

For dependable, continuing operations of pallet missions with flight intervals of two to four months, it appears that three (3) complete pallet systems (shipsets) are needed. This number is a minimum if two are to be in ready condition to insure the launch schedule.

Each camera system is expected to require refurbishment after several flights which will make it unavailable for flight for a period of about 12 months. If a launch interval of as short as two months is to be supported while one camera is in rework (and three is the total camera inventory, one for each pallet), then as shown, a 30 day rework/system test cycle is needed to provide the launch backup. A more realistic cycle, providing 60 to 90 days for rework and system test, requires relaxation of the backup requirement or the addition of a fourth camera to the inventory to allow interchange of cameras among the three pallets.

The number of flights possible before refurbishment of a camera is uncertain at this time. The table on the chart shows the number of months available for refurbishment as a function of the total number of flights per year and the number of flights before refurbishment of each of three cameras. In the region where available refurbishment time is less than 12 months, a fourth camera would be needed (independent of the question of launch backup availability).

The significance of these considerations is that a pallet system for extensive continuing operations requires a large amount of hardware which spends most of its life on the ground in storage or being made ready for flight.

Pallet operations may be economically feasible only with greater intervals between flights, averaging four months or more to allow flight-to-flight turn around of a single system. Two ship-sets would be needed initially to provide a launch backup and a third camera could be added after two or three years while the first was being refurbished. Alternately, the initial two systems might support a dozen or so flights over a three to four year period, awaiting development of an advanced free-flyer. Later reworks of the pallet camera to free-flyer cameras could be considered.

PALLET SYSTEM — OPERATIONAL CYCLING

ASSUMPTIONS:

- LAUNCH INTERVALS OF TWO TO FOUR MONTHS
- 3 FLIGHT SYSTEMS (COMPLETE PALLETS)
- PERIODIC CAMERA REFURBISHMENT REQUIRES APPROXIMATELY 12 MONTH
- 2 SYSTEMS IN READY CONDITION DESIRED FOR EACH LAUNCH

TYPICAL TURN-AROUND SEQUENCES (EACH SYSTEM)

3 CAMERAS, LAUNCH BACKUP:

3 CAMERAS, BACKUP NOT ALWAYS AVAIL
(OR 4 CAMERAS, BACKUP AVAILABLE)

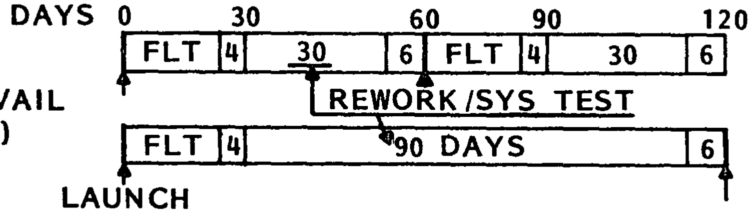

TABLE OF MAXIMUM DOWN TIME FOR REFURB. (3 CAMERAS)

	FLIGHTS PER YEAR:	3	4	5	6
FLIGHTS ON EACH CAMERA BEFORE REFURBISHMENT	4	15	11	8.6	7
	6	23	17	13.4	11
	8	31	23	18.2	15

4TH CAMERA INDICATED

INTERIM FREE-FLYER CONCEPTS

WTR free-flyer evolutionary concepts can meet the intelligence requirements for 1984 and beyond by initially using silver-halide film retrieval with growth potential to incorporate advanced technologies for near real-time data return.

The free-flyer offers the capability for flexible operations, allowing maximum shuttle sharing opportunities. However, the key *cost driver* for the interim free-flyer is the availability of shared shuttle opportunities specifically for film retrieval. It should be noted that the *advanced technology free-flyer* incorporating near real-time readout is significantly less sensitive to the availability of shared shuttle opportunities.

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INTERIM FREE-FLYER CONCEPTS

SV CHARACTERISTICS

8300 LB
1 YR LIFE OR MORE
500 LB FILM
1500 LB PROPELLANT

THREE SV CLUSTER SYSTEM PROVIDES

- EXCELLENT TARGET ACCESS
- NIIRS-5 AND -4 PERFORMANCE
- FLEXIBLE SHUTTLE OPERATION:
  - MAXIMIZES SHARING OPPORTUNITIES
  - MINIMIZES "SHIP SETS" NEEDED
- IMPROVED SURVIVABILITY
- ALLOWS TECHNOLOGY IMPROVEMENTS

PERFORMANCE SUMMARY

QUALITY – 130 NM ALTITUDE FOR NIIRS-5
170 NM ALTITUDE FOR NIIRS-4

QUANTITY – EXCEED MID-1980s SEARCH REQUIREMENTS

INTERIM FREE-FLYER CONSIDERATIONS

While the performance and evolutionary potential of the interim free-flyer concept is attractive, there are a number of considerations which could drive its cost beyond the point of economic feasibility. These need investigation to support a recommendation on the choice between the ETR pallet concept and the WTR free-flyer concept for the time period from 1984 to perhaps 1988.

The cost of the first option for meeting the two-month data return requirement, i.e., six shuttle operations per year, will be prohibitive unless ride-sharing can be extensively exploited. Since the free-flyer inclination (sun-synchronous) and launch-time are critical, the likelihood of extensive sharing is small. The most attractive possibility is the use of other resources, that is, that SCS requirements be relaxed in light of capability of other planned systems. If requirements can be relaxed enough, including deletion of high latitude targets from SCS requirements, the 57° (ETR) Pallet approach would be adequate and, since it involves less development cost, would become the more desirable approach.

Concept design of film retrieval, refueling and maintenance approaches has shown that interim free flyers will be quite complex. Preliminary data is provided in an appendix under separate cover.

INTERIM FREE-FLYER CONSIDERATIONS

TWO MONTH DATA RETURN REQUIREMENT – OPTIONS

- SIX SHUTTLE OPERATIONS/YR
- USE OF RECOVERY VEHICLES (RVs) FOR NEAR-TERM SOLUTION
- USE OF OTHER RESOURCES

COST DRIVERS

AVAILABILITY OF SHARED SHUTTLE OPPORTUNITIES

- SPECIFICALLY FOR FILM RETRIEVAL

SHUTTLE SUPPORT

- FILM CASSETTE EXCHANGE
- RE-FUELING PROPELLANTS
- MAINTENANCE
- ASTRONAUT INTERFACE

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APPENDIX A

CONFIGURATION AND DESIGN ALTERNATIVES

CONFIGURATION AND DESIGN ALTERNATIVES

INTRODUCTION

This appendix presents the results of design activity in two areas: (1) pallet configuration using the initial SCS camera designs which had a scan capability of approximately ± 16° and (2) interim free-flyer designs using silver halide film cameras with ± 40° scan capability.

The ± 16° pallet configuration data were not included in Volume I because these configurations are not recommended. The reasons for rejecting these concepts include the accommodation difficulties and operational penalties identified in the data provided here. In addition, as shown in the performance analysis reported in Volume I, especially for the short missions of pallets, the ± 16° scan provides very inferior quantity performance compared to ± 40° scan, for which SCS camera design penalities are acceptable. Volume I, then, presents design data for the ± 40° cases (2 camera concepts) only.

A more surprising result of the performance analysis is that, even for free flyers with longer life missions, the performance penalties for ± 16° scan are unacceptable. This result is particularly so in poor weather regions and when the data are required at two month intervals. For this reason a scan angle of ± 40° is recommended for both pallet and free-flyer configurations.

CONFIGURATION AND DESIGN ALTERNATIVES (CONT.)

The free-flyer design data presented in the latter portion of this Appendix, therefore, shows concepts using ± 40° scan capability. This has the advantage in design of the vehicle that high maneuver rates are not required. Hence, momentum wheels can be considered for attitude control rather than the more complex CMGs.

A major conclusion of the study is that the interim free-flyer configuration is not an attractive alternative (even though its performance is excellent), largely because of the extensive dead-end costs implied by the complexity of film retrieval and refueling systems indicated by the preliminary design data shown here. (Another factor is the low likelihood of sufficient ride-sharing opportunities into sun sychronous orbits for film retrieval in order to avoid the costly use of dedicated STS operations.) Since it appears that an interim free-flyer would have a short operational life (about 2 to 4 years), it is not likely that sufficient operational savings could accrue to justify the additional development costs of an interim free-flyer compared to pallet systems.

SHUTTLE ROLL FOR OBLIQUITY

To get oblique or off nadir photography using a camera with small scan angle (e.g. ± 16°), two methods are available. One is to roll the whole vehicle,the other is to gimbal the camera. Both have advantages and disadvantages.

Rolling the whole shuttle vehicle has the main advantage of a simpler payload installation. However, it is expensive in fuel in that the whole vehicle must be rolled over and back for every oblique take. And for reasonable fuel consumption the response is slow.

The major pros and cons are identified on the chart. Note that the null orientation shows the vehicle rolled 55° off of directly upside down. This is necessary to allow a ± 30° roll and also to provide good visibility for the star sensors. The installation shown is typical and not necessarily totally optimized.

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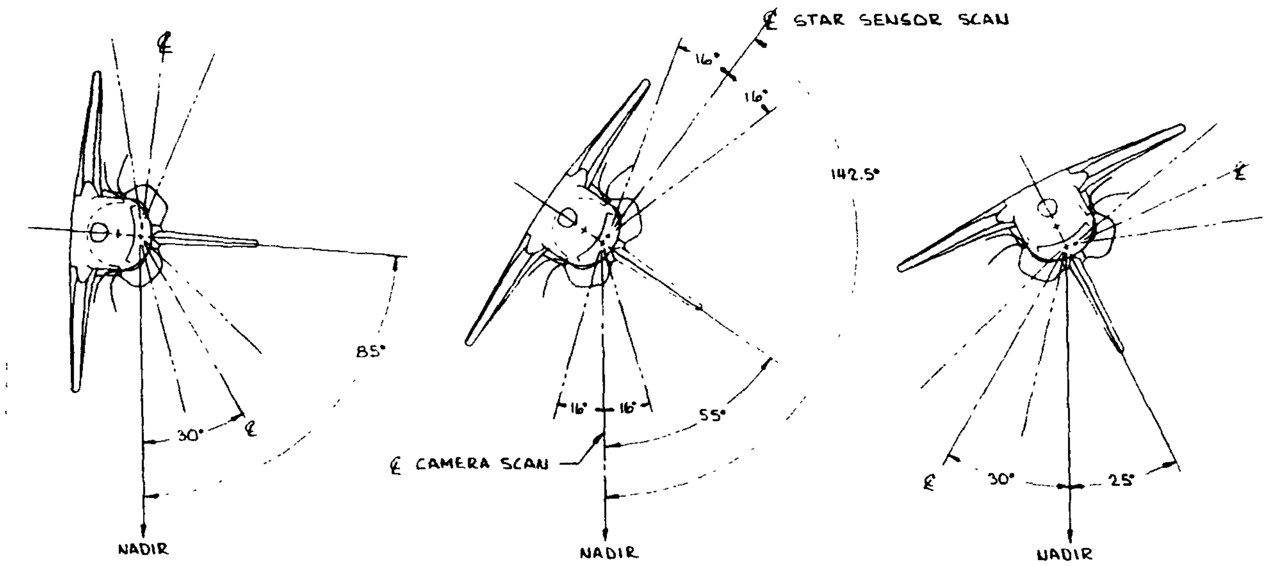
SHUTTLE ROLL FOR OBLIQUITY



ADVANTAGES

- FIXED CAMERA INSTALLATION
  - SIMPLER AND LESS COSTLY THAN GIMBLED CAMERA
- MINIMUM USE OF PAYLOAD BAY LENGTH
  - MORE RIDE-SHARE FLEXIBILITY
  - MAY REDUCE LAUNCH COST

DISADVANTAGES

- LIMITED NUMBER OF ROLLS
  - AVAILABLE ATTITUDE CONTROL PROPELLENTS LIMITED
- SLOW RESPONSE FOR OBLIQUITY CHANGES
- COORDINATION THROUGH JSC FOR MANY ATTITUDE CHANGES

GIMBALLED CAMERA FOR OBLIQUITY

The main advantages of the gimballed camera concept are speed of response and less use of attitude control fuel. However, the installation is more complex and requires additional space in the bay. Note that the null orientation has the shuttle rolled over so that it is about 40° away from directly upside down.

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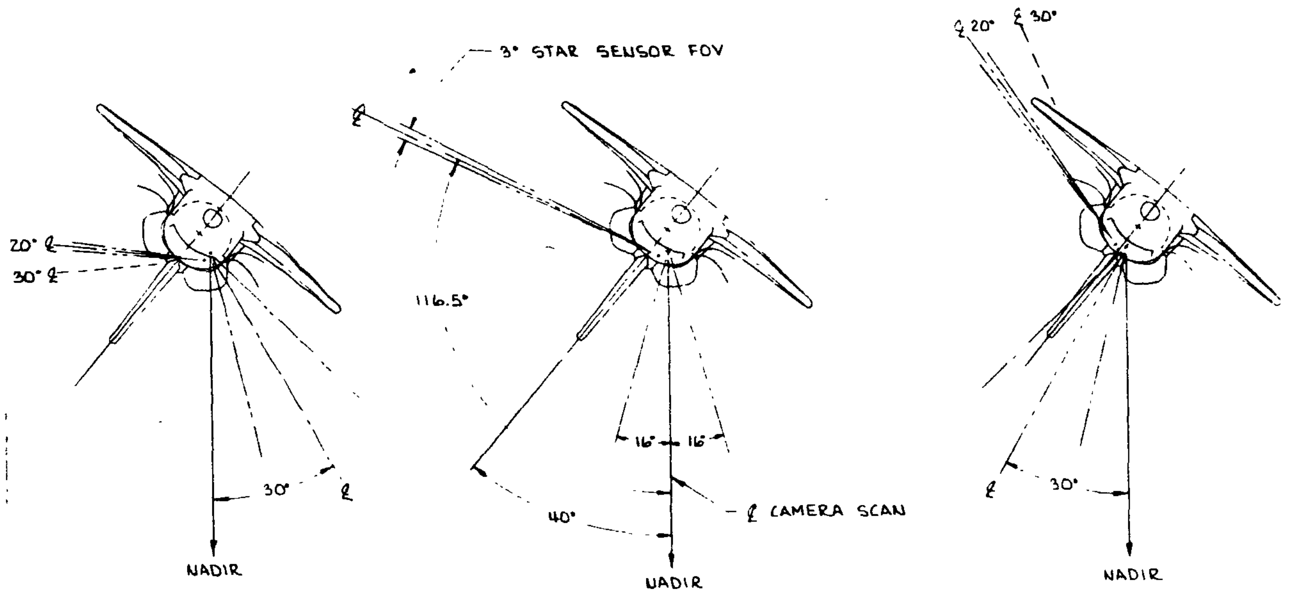
GIMBALLED CAMERA FOR OBLIQUITY



ADVANTAGES

- FIXED ORBITER ATTITUDE
- FAST RESPONSE FOR OBLIQUITY CHANGES
- MINIMUM ATTITUDE CONTROL PROPELLANT USAGE

DISADVANTAGES

- COMPLEXITY OF GIMBALED INSTALLATION
- INCREASED USE OF PAYLOAD BAY LENGTH

FOUR PALLET CONFIGURATIONS WITH ±16° SCAN

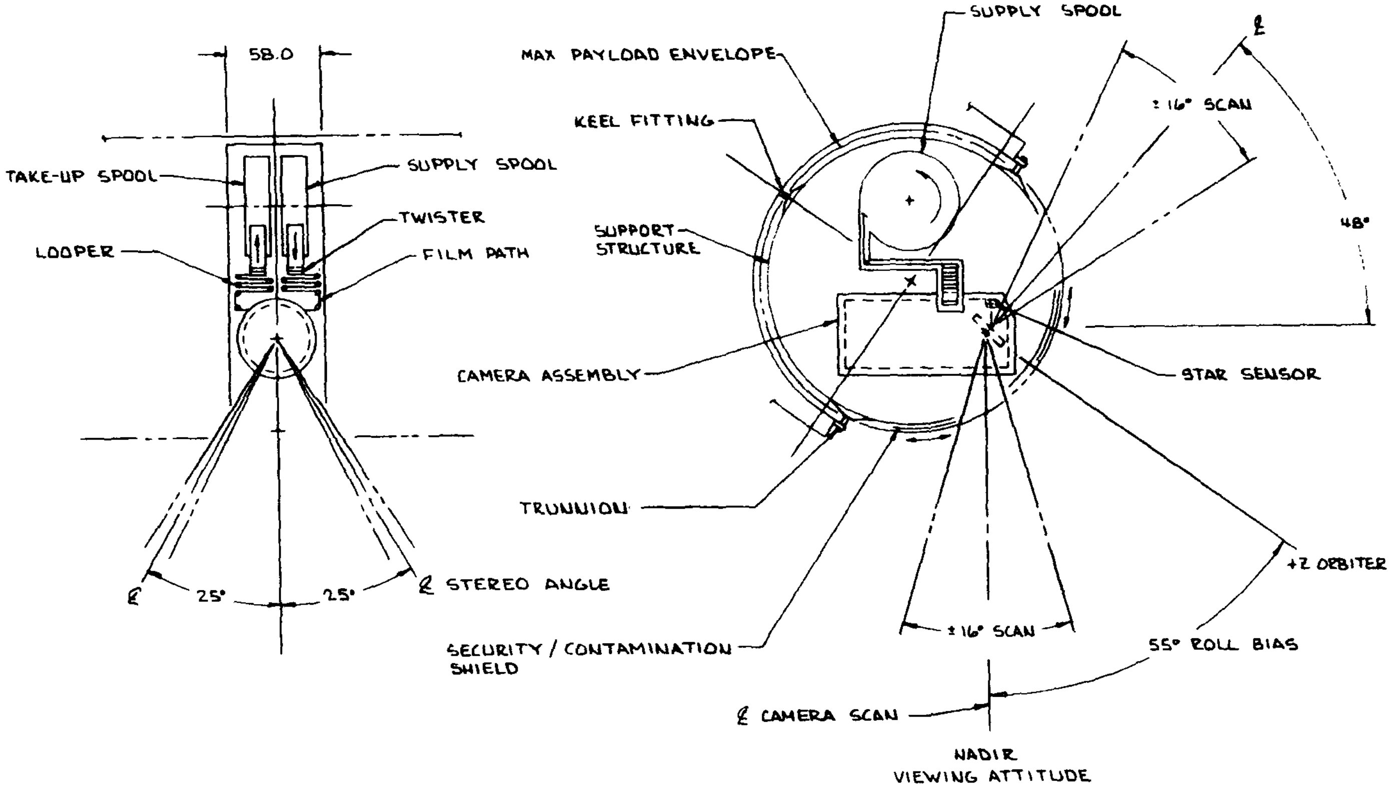
The following six charts are entitled:

Camera #1 - Shuttle Roll
Camera #2 - Shuttle Roll
Camera #1 - Gimballed
Camera #2 - Gimballed
Life Reduction for Roll Maneuvers - Fuel Cells Only
Life Reduction for Roll Maneuvers - With Solar Panels

The first four represent concept designs for alternative pallet system installations using SCS camera with ± 16° scan. The last two present Rockwell estimates of the penalty to orbit life (or shared payload capability) resulting from use of the shuttle roll concept for obtaining oblique imagery.

In all cases a roll bias is used to obtain acceptable view angles for both the SCS camera and the star sensors. These approaches are all technically feasible but none is considered desirable. The gimballed camera approaches involve complex film supply problems and the shuttle roll cases involve slow response or significant mission-life/shared payload reductions. The penalties to camera design for increasing the scan to ± 40° appear no more severe and the resulting performance is far superior.

CAMERA #1 — SHUTTLE ROLL



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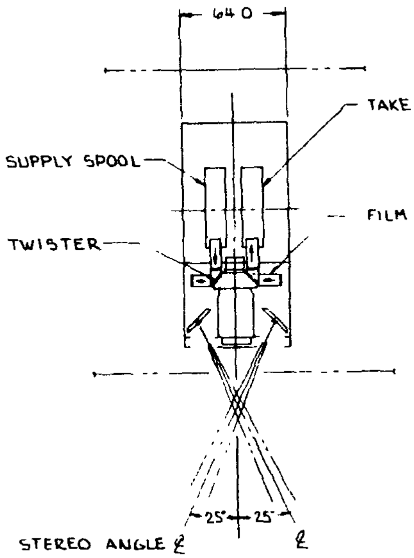
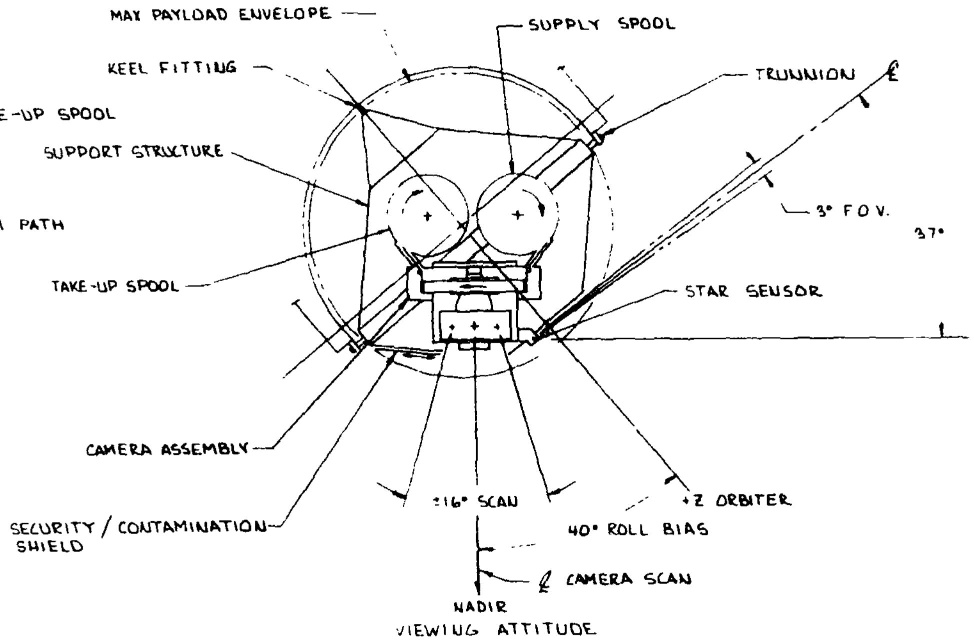
CAMERA #2 — SHUTTLE ROLL





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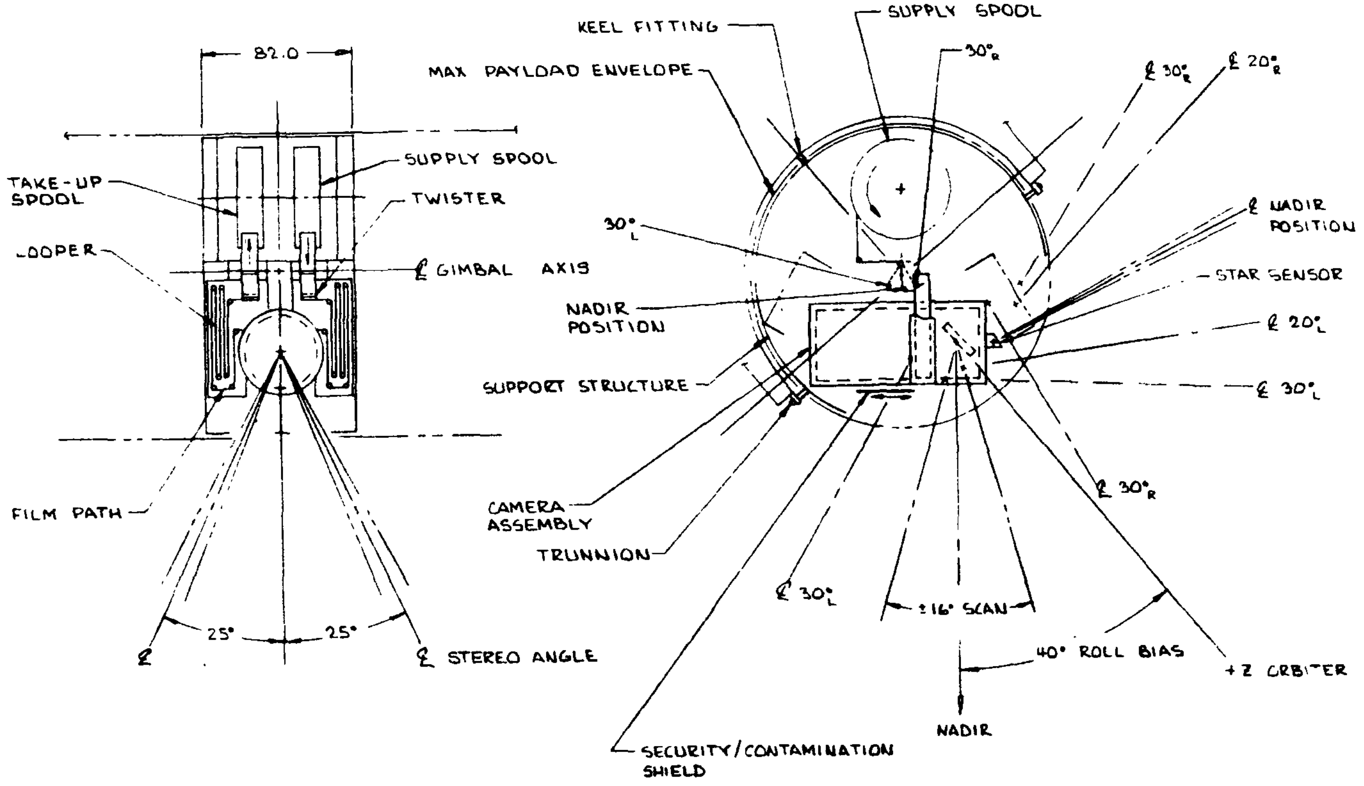
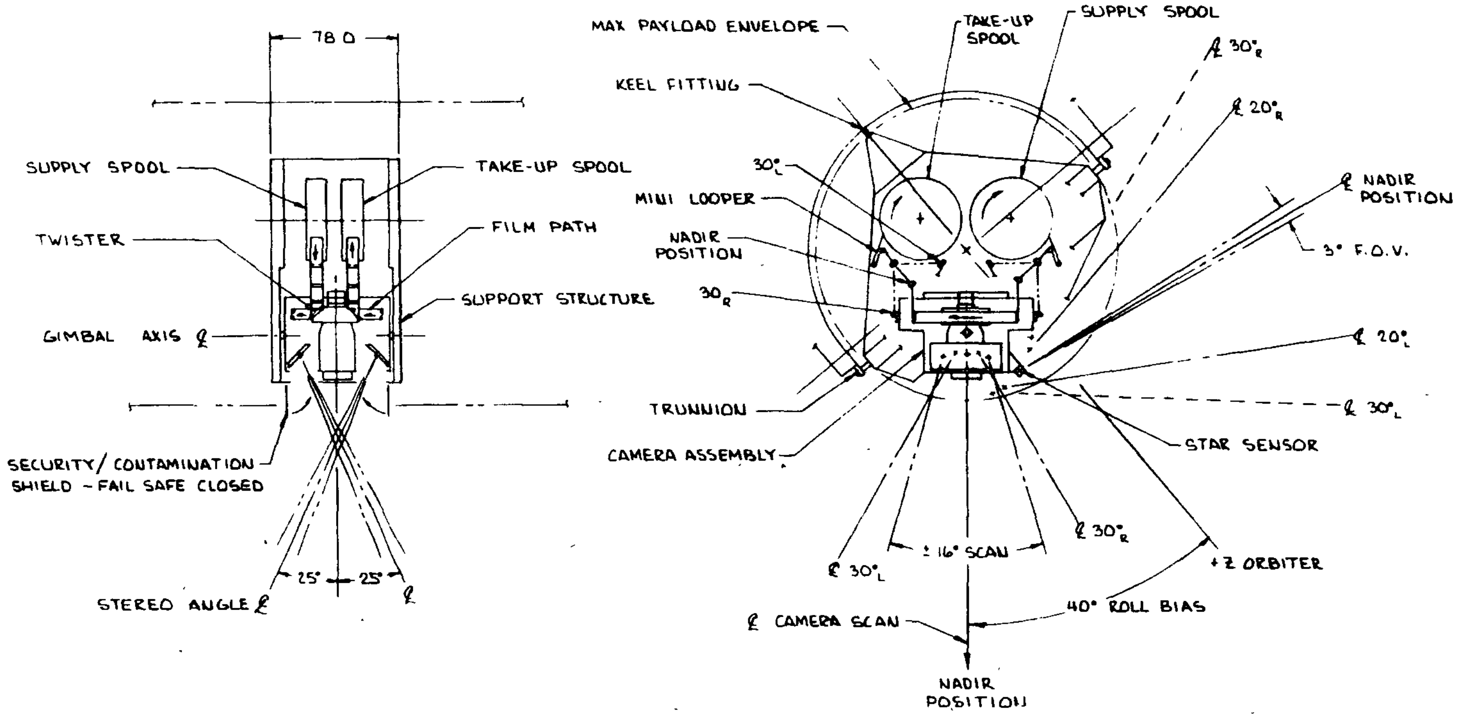
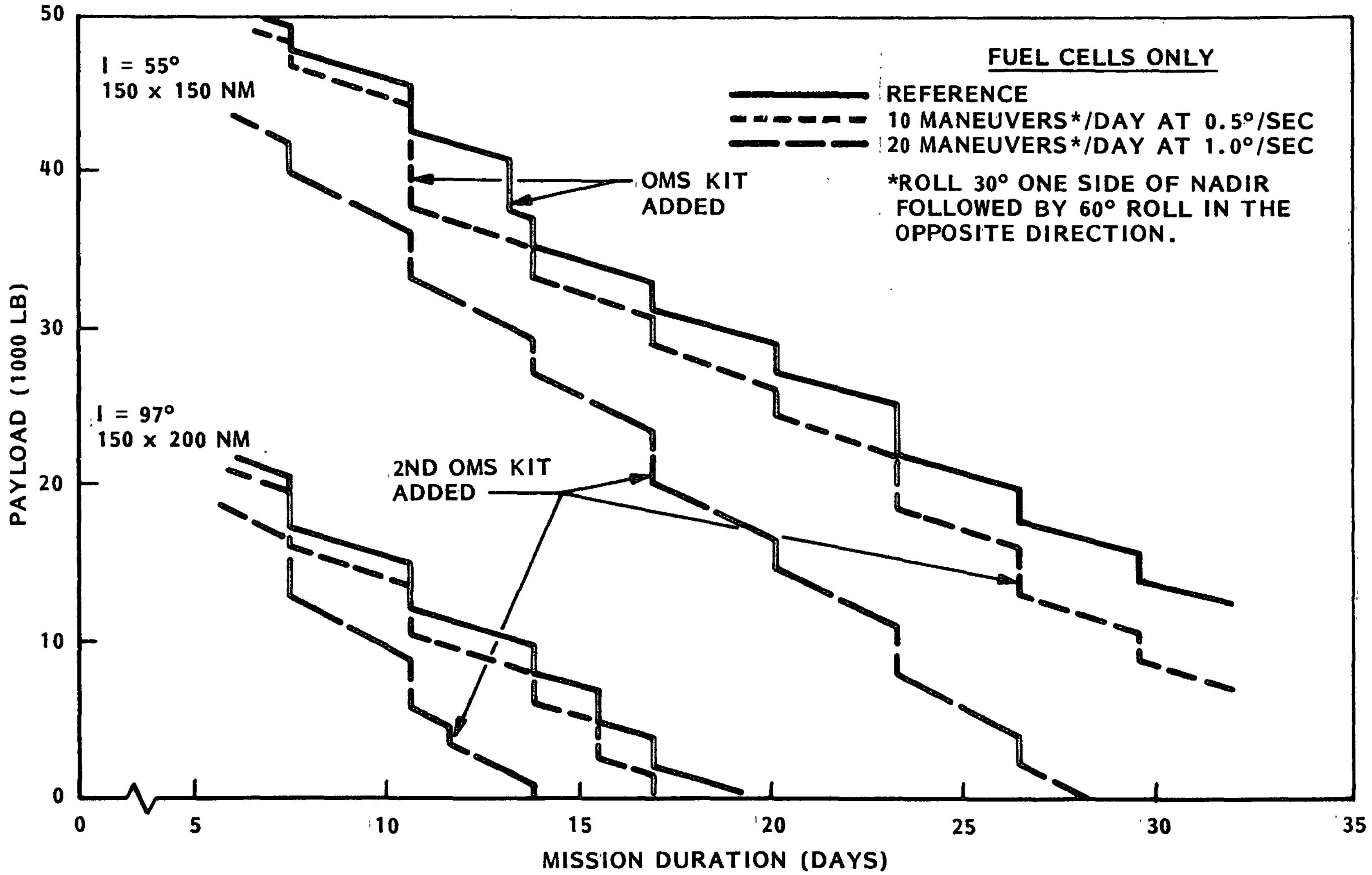
CAMERA #1 – GIMBALLED



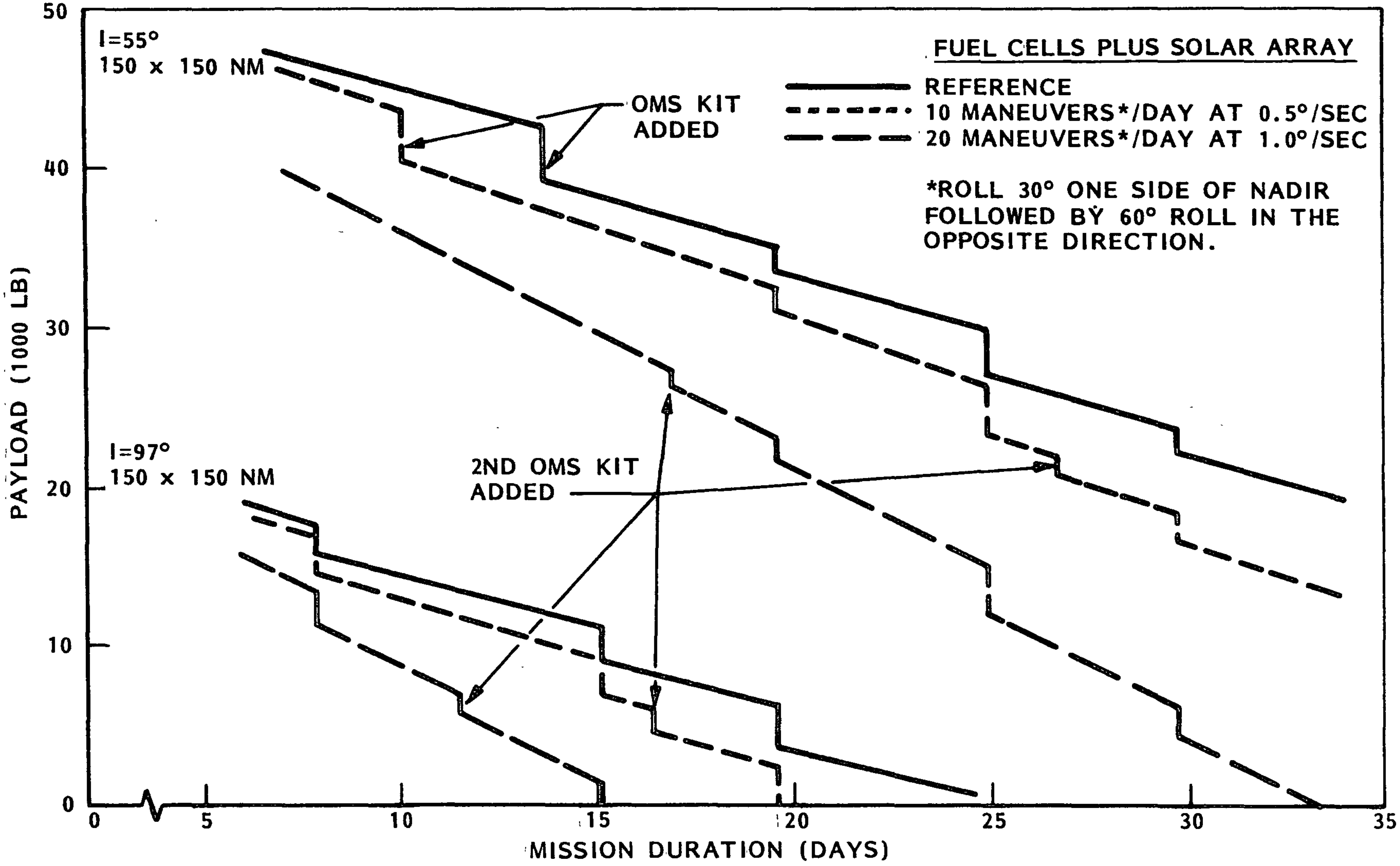
CAMERA #2 – GIMBALLED



LIFE REDUCTION FOR ROLL MANEUVERS



LIFE REDUCTION FOR ROLL MANEUVERS



INTERIM FREE FLYER - CAMERA NO. 1

A preliminary layout is shown in Drawing No. 6161001. The camera system consists of a lens assembly and a film cassette. The cassette contains the supply, take up, loopers, and platen assembly. The film supply/take up spools are packaged efficiently by utilizing air bars at the exit/entrance of the respective spools. The dimensions of the camera system are 57" x 85" x 145". The cassette system provides the necessary interfaces to facilitate module exchange on orbit. The interface system includes precision ground registration surfaces, latches, and RMS end effector receptor. (The latter is the device which interfaces with the Remote Manipulator System (RMS) of the Shuttle.)

The camera system is surrounded by the environmental control enclosure, which also provides security for the prelaunch environment.

Star sensors are included which, along with a GPS unit, provide data to satisfy MC&G requirements. The star sensor data is also used for vehicle attitude reference.

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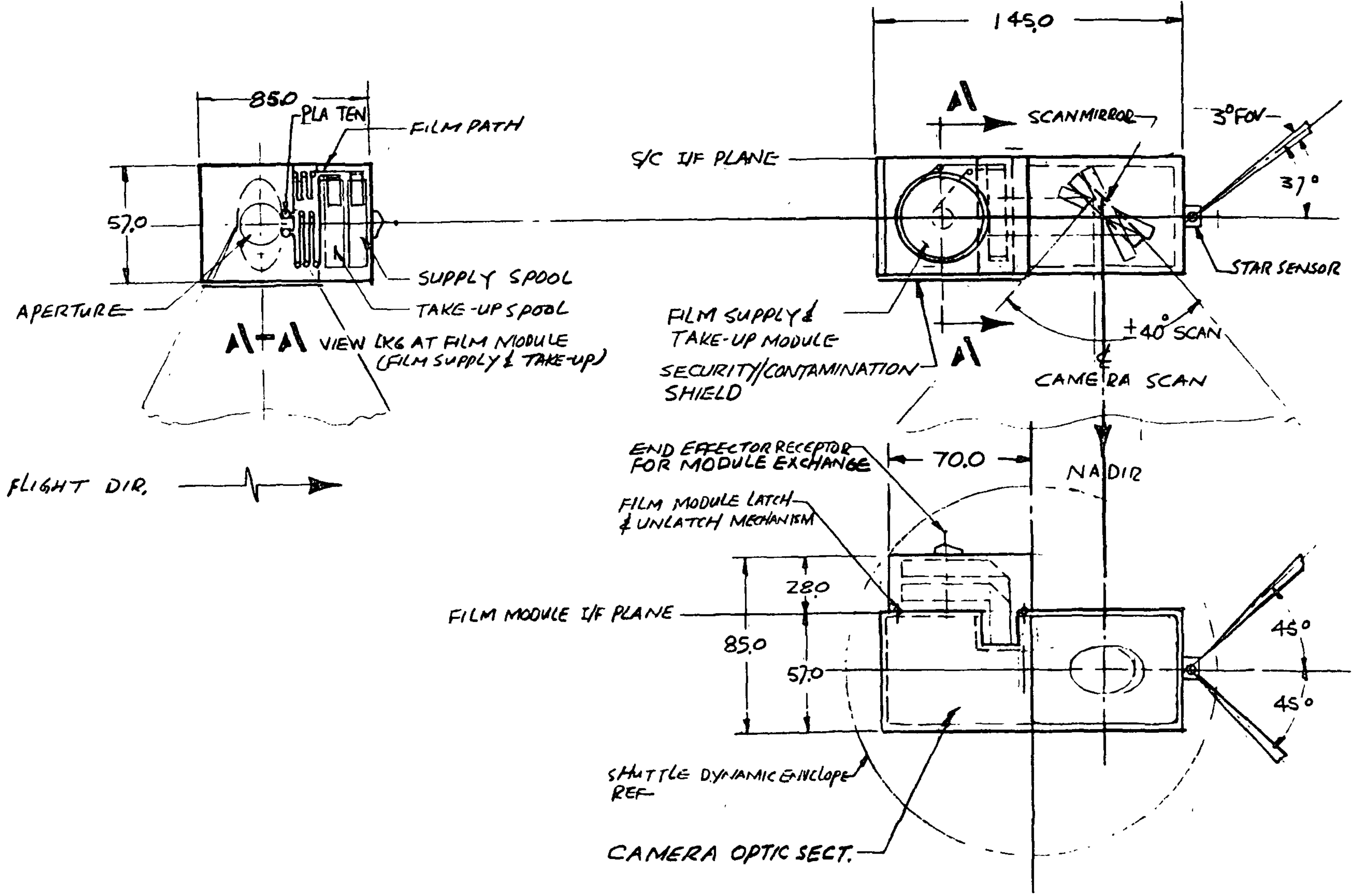
REV A

INTERM FREE FLYER CAMERA I
FILM MODULE EXCHANGE CONCEPT



~~SECRET/~~10418/HEXAGON

DRAWING NO. 6161001

INTERIM FREE FLYERS - CAMERA NO. 2

A preliminary layout is shown in drawing no. 6161002. The camera system consists of the lens assembly and two film cassettes, one for each side. The cassettes contain supply and take up spools, loopers and guide rollers which interface with the camera platen. In concept #2, the platen remains with the lens assembly. No twists are required for efficient packaging. The dimensions of the camera system are 65 by 80 by 130 inches. The cassette system provides the necessary interfaces to facilitate module exchange on orbit. The interface includes precision ground registration surfaces, latches, and RMS end effector receptor.

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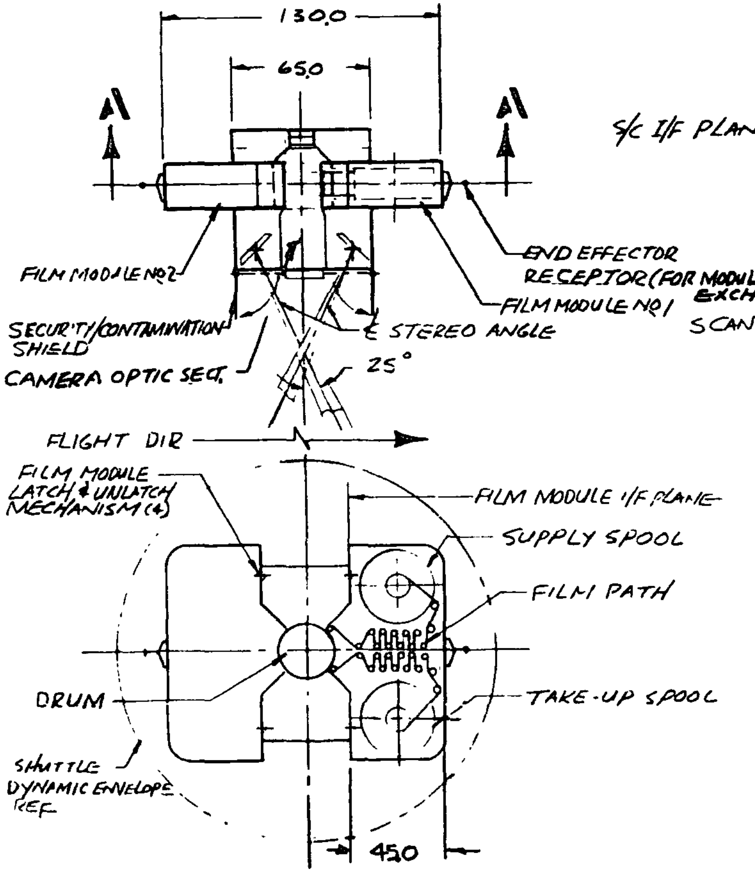
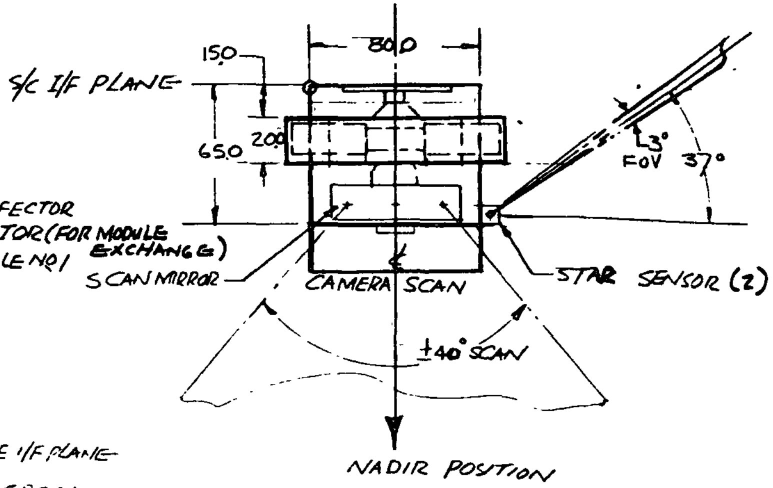
INTERM FREE FLYER CAMERA 2
FILM MODULE EXCHANGE CONCEPT

DRAWING NO. 6161002



A - A
VIEW LOOKING AT FILM MODULE
(FILM SUPPLY AND TAKE-UP)



SCS FREE FLYER CONFIGURATIONS

The SCS free flyer configurations consist of forward mounted camera, deployable solar arrays, antennas, and spacecraft subsystem equipment support structure selection. The preliminary concepts for the Interim Free Flyer Camera 1 and 2 are presented in drawings 6161003 and 6161004, respectively.

The preliminary spacecraft structure selected is based on maximum utilization of flight proven hardware to provide a minimum development span. It uses LMSC Space Telescope (ST) program designs now under development for early 1980's flight on the space Transport System (STS). The designs have proven flexibility ease in maintainability and compatibility with shuttle interfaces. Preliminary study shows that the camera assembly easily integrates and interfaces into the spacecraft structure. The design provides flexibility for external installation, removal, or exchange of film modules in ground or orbital operation. Growth space is also provided for additional camera or spacecraft subsystem equipment.

Spacecraft Structures Subsystem Equipment Support Section. The spacecraft structure section overall size is 168 in. dia, 40 in. long cylinder and consists of forward and aft bulkheads with 12 peripheral bays using sheet metal construction. These structural assemblies support, house, and protect all subsystem equipment and carry the launch, ascent, orbit, and reentry loads. Each bay has removable exterior panels for access to the equipment area. Section A-A shows the overall basic equipment arrangement of principal component items.

A modular equipment installation concept provides flexibility for location and removal of components. Each equipment module can be functionally tested as a unit prior to qualification of the total system. Mechanical and electrical interfaces for each equipment module can be defined and controlled with respect to the remainder of the spacecraft systems. Thus, flexibility is provided for integration of the camera subsystem with spacecraft equipment. The space in the center bay behind the peripheral equipment bay is also available for back mounting of additional equipment.

Solar array, antenna and engine subsystems are mounted on the zenith sides of the spacecraft, providing a clear full field of view. At launch and when shuttle orbiter revisits for maintenance operations, the solar array and antennas are retracted and stowed in the aft end of the spacecraft.

Orbital Configuration. Drawings 6161003 and 6161004 also present the Interim Free Flyer orbital configurations. The GPS and space communication link antennas have been deployed, and the solar array panels have been extended outward along the x-axis. The overall dimensions of the in-orbit configuration of the spacecraft are 145 in. length by 340 in. span across the solar array panels.

Weight Summary. Table 1 presents a preliminary estimated weight summary of all subsystem elements, required contingency, and total Camera 1 and 2 spacecrafts weight at launch. This preliminary weight is within the shuttle STS performance capability and allows launch of up to three spacecraft on the same flight.

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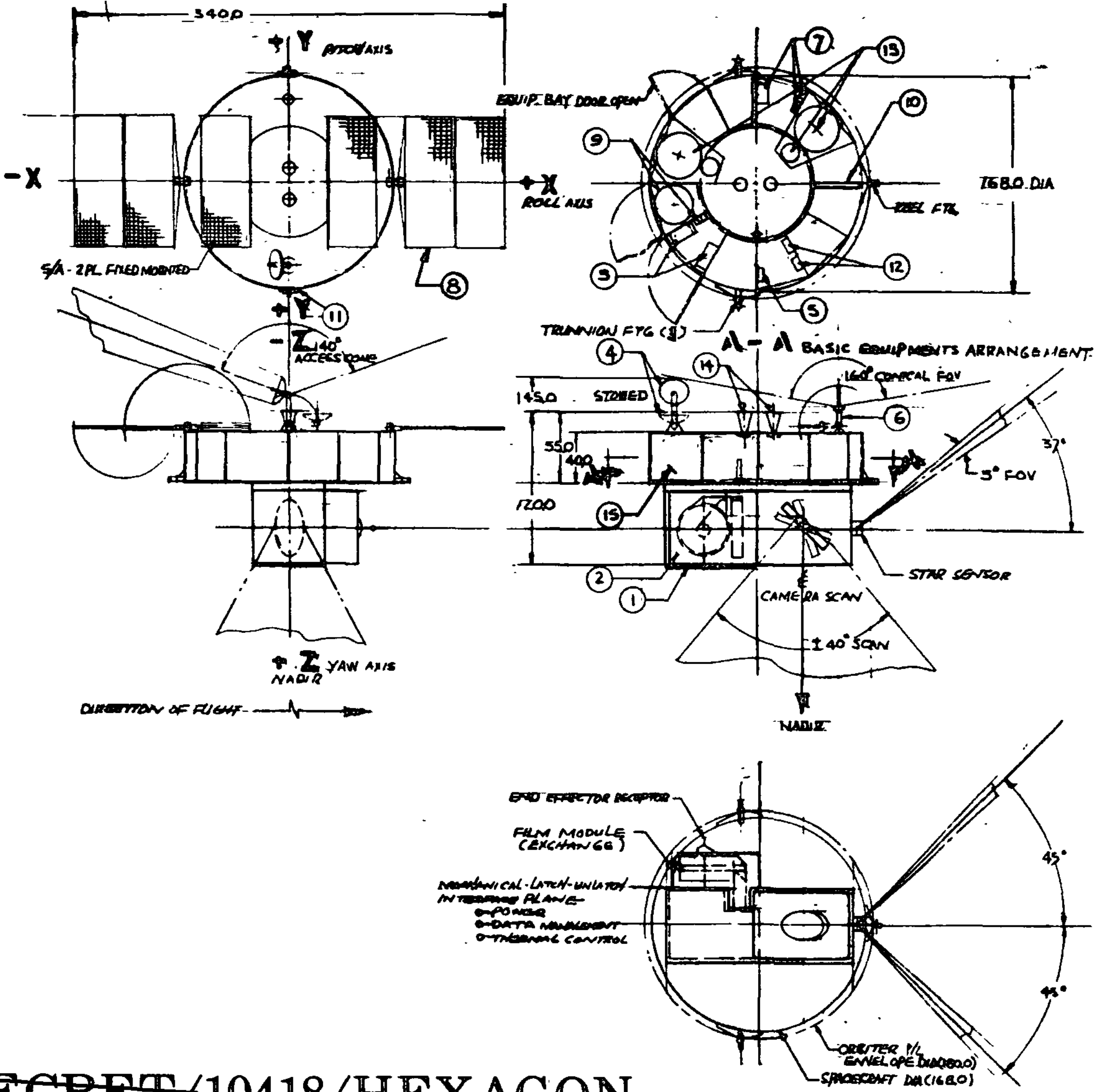
REV A

INTERM FREE FLYER CAMERA 1 FILM MODULE EXCHANGE S/C SUPPORT SYSTEM CONCEPT

SUBSYSTEM COMPONENTS

ITEMS	COMPONENTS
①	CAMERA ASSY
②	FILM MODULE ASSY
③	SPACE COMMUNICATION LINK • RECEIVER • TRANSMITTER
④	SPACE COMM LINK ANTENNA (2 AXIS GIMBAL)
⑤	GPS • RECEIVER • COMPUTER
⑥	GPS ANTENNA (DEPLOYABLE)
⑦	ELECTRICAL POWER • BATTERY • CHARGE CONTROLLER • DISTRIBUTION & CONTROL • REGULATOR • I/F CONTROL ELECTRONIC
⑧	SOLAR ARRAY ASSY (2 AXIS TRACKING WING)
⑨	ATTITUDE CONTROL • MOMENTUM WHEELS • CONTROL ELECTRONIC • COMPUTER
⑩	MAGNETIC TORQUERS
⑪	RCS / THRUSTERS/PLUMBING.
⑫	TELEMETRY & COMMAND • RECORDER • TEL. TRACKING & COMM BOX
⑬	PROPULSION • TANK ASSY, He TANK & PLUMBING • FUEL (MMH) OXIDIZER (N2O4)
⑭	ENGINE SYSTEM • BIPROPELLANT • 100 LBS THRUST
⑮	STRUCTURE/MECHANICAL ASSY ELECTRICAL HARNESS & CONNECTOR



DRAWING NO. 6161003

INTERN FREE FLYER CAMERA 2 FILM MODULE EXCHANGE S/C SUPPORT SYSTEM CONCEPT

DRAWING NO.
6161004

SUBSYSTEM COMPONENTS

ITEMS	COMPONENTS
①	CAMERA ASSY
②	FILM MODULE ASSY
③	SPACE COMMUNICATION LINK • RECEIVER • TRANSMITTER
④	SPACE COMM LINK ANTENNA (2 AXIS GIMBAL)
⑤	GPS • RECEIVER • COMPUTER
⑥	GPS ANTENNA (DEPLOYABLE)
⑦	ELECTRICAL POWER • BATTERY • CHARGE CONTROLLER • DISTRIBUTION & CONTROL • REGULATOR • I/F CONTROL ELECTRONIC
⑧	SOLAR ARRAY ASSY (2 AXIS TRACKING WING)
⑨	ATTITUDE CONTROL • MOMENTUM WHEELS • CONTROL ELECTRONIC • COMPUTER
⑩	MAGNETIC TORQUERS
⑪	RCS / THRUSTERS/PLUMBLING
⑫	TELEMETRY & COMMAND • RECORDER • TEL. TRACKING & COMM BOX
⑬	PROPULSION • TANK ASSY, He TANK & PLUMBING • FUEL (MMH) OXIDIZER (N_2O_4)
⑭	ENGINE SYSTEM • BIPROPELLANT • 100LBS THRUST
⑮	STRUCTURE/MECHANICAL ASSY ELECTRICAL HARNESS & CONNECTOR

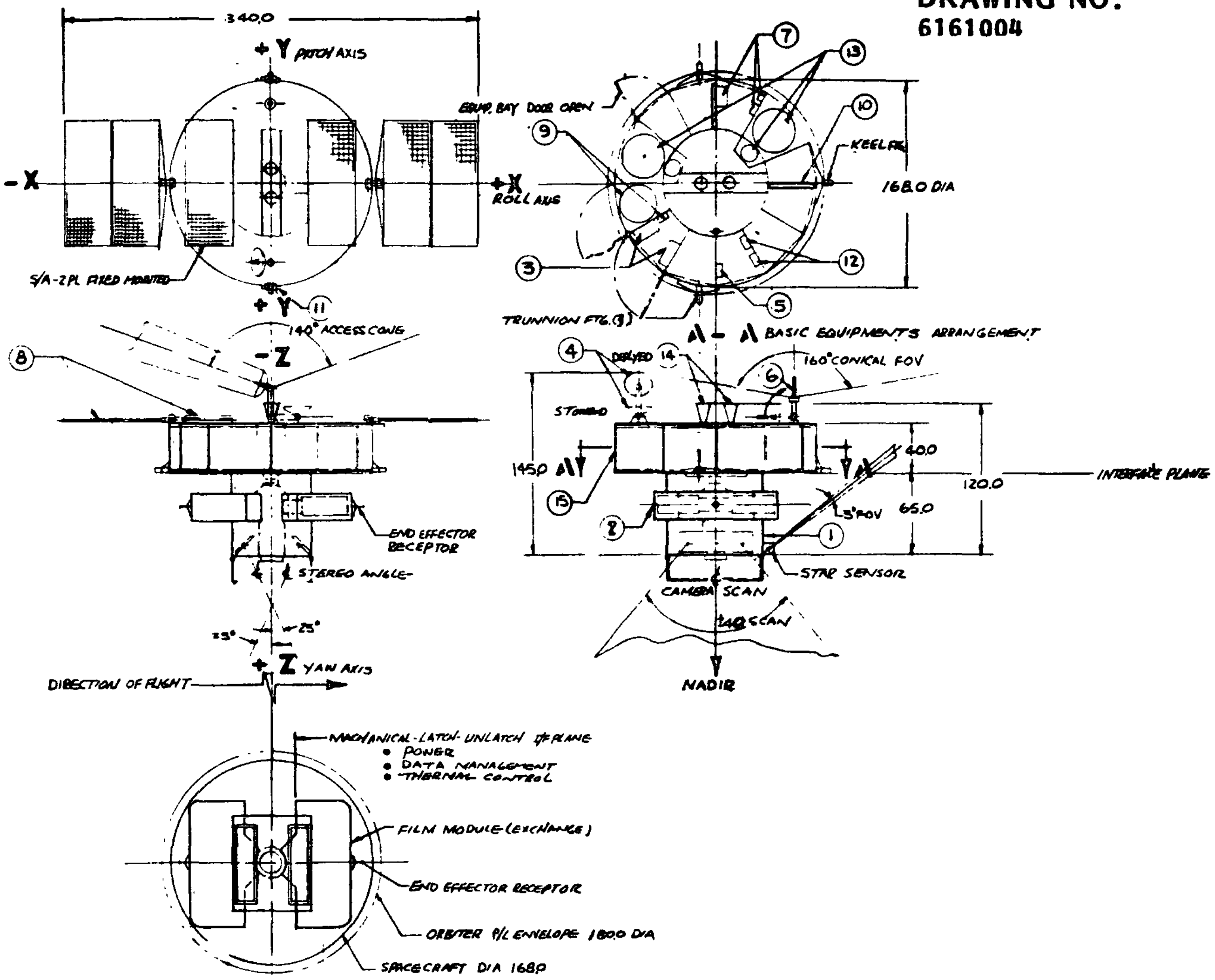


Table 1

WEIGHT SUMMARY

SUBSYSTEM ITEM	CONCEPT FREE-FLYERS INTERIM WT-LB	
	CAMERA 1	CAMERA 2
SPACECRAFT STRUCTURE & MECHANISM ASSY	1,400	1,400
CAMERA ASSY (OPTIC SECTION)	800	1,300
FILM MODULE ASSY (TAK-UP, SUPPLY SPOOLS & STRUCTURE MECH)	400	690
SPACE COMM LINK	250	250
GPS SYSTEM	50	50
ELECTRICAL POWER	700	700
ATTITUDE CONTROL (INCL MOMENTUM WHEELS & RCS)	280	280
TELEMETRY & COMMAND	150	150
PROPULSION DRY	400	400
SUBTOTAL	4,430	5,220
CONTINGENCY (20%)	886	1,044
FILM LOAD	500	500
PROPELLANT	1,500	1,500
TOTAL WEIGHT AT LAUNCH	7,316	8,264

FREE FLYER LAUNCH AND DEPLOYMENT CONCEPT

Preliminary layout of a three spacecraft launch configuration in a single shuttle is shown in drawing 6161005.

Spacecraft/Shuttle Orbiter (STS) Interface. Drawing 6161005 presents the installation of three interim free flyers in the orbiter 15 ft dia, 60 ft long cargo bay. The free flyers take approximately 60% of the cargo bay. The drawing shows the standard interface attachment points. At launch the free flyer is attached to the cargo bay by a four-point retention as shown in View B. Attachment fittings along the longerons take loads in both the ±X and ±Z directions (primary) or the ±Z direction (stabilizing), while the lower keel fittings react loads in the ±Y direction (auxiliary) only. This spacecraft attachment retention scheme is the nominal orbiter baseline approach and is readily adaptable to existing loads-analysis computer programs. All spacecraft attachments are of the trunnion/journal type. Remotely activated journals are used to secure and release the spacecraft for on-orbit deployment/retrieval. To assist in final spacecraft placement retrieval, a flared alignment guide is provided. It is stowed when not in use as shown in View B of drawing 6161005. The keel fitting assembly includes a self-aligning ball bushing mounted in a race which can slide freely in the X-direction through a tee-slot provided in the main body of the keel fitting in orbiter. Engagement/disengagement of this fitting with the 3-in. dia keel pin extending from the spacecraft is achieved by straight Z-motion.

Deployment of Spacecraft. At present, NASA indicates that the RMS (Remote Manipulator System) will be capable of "removing and installing: a 15 ft dia, 60 ft long, 65,000 lb payload. A configuration illustrating free flyer camera spacecraft in the orbiter payload bay is presented in drawing 6161005 for RMS handling only. In this installation configuration, the spacecraft is optimally located for CG. The RMS grasps the spacecraft grapple fixture, the active spacecraft retention mechanisms are unlatched, and the RMS then is activated to extract the spacecraft from the cargo bay above the orbiter and is released to orbit by the RMS. For capture and retrieval the RMS first grasps the grapple fixture and "lowers" the spacecraft into the cargo bay. The retention mechanisms are then locked and the RMS releases from the grapple fixture.

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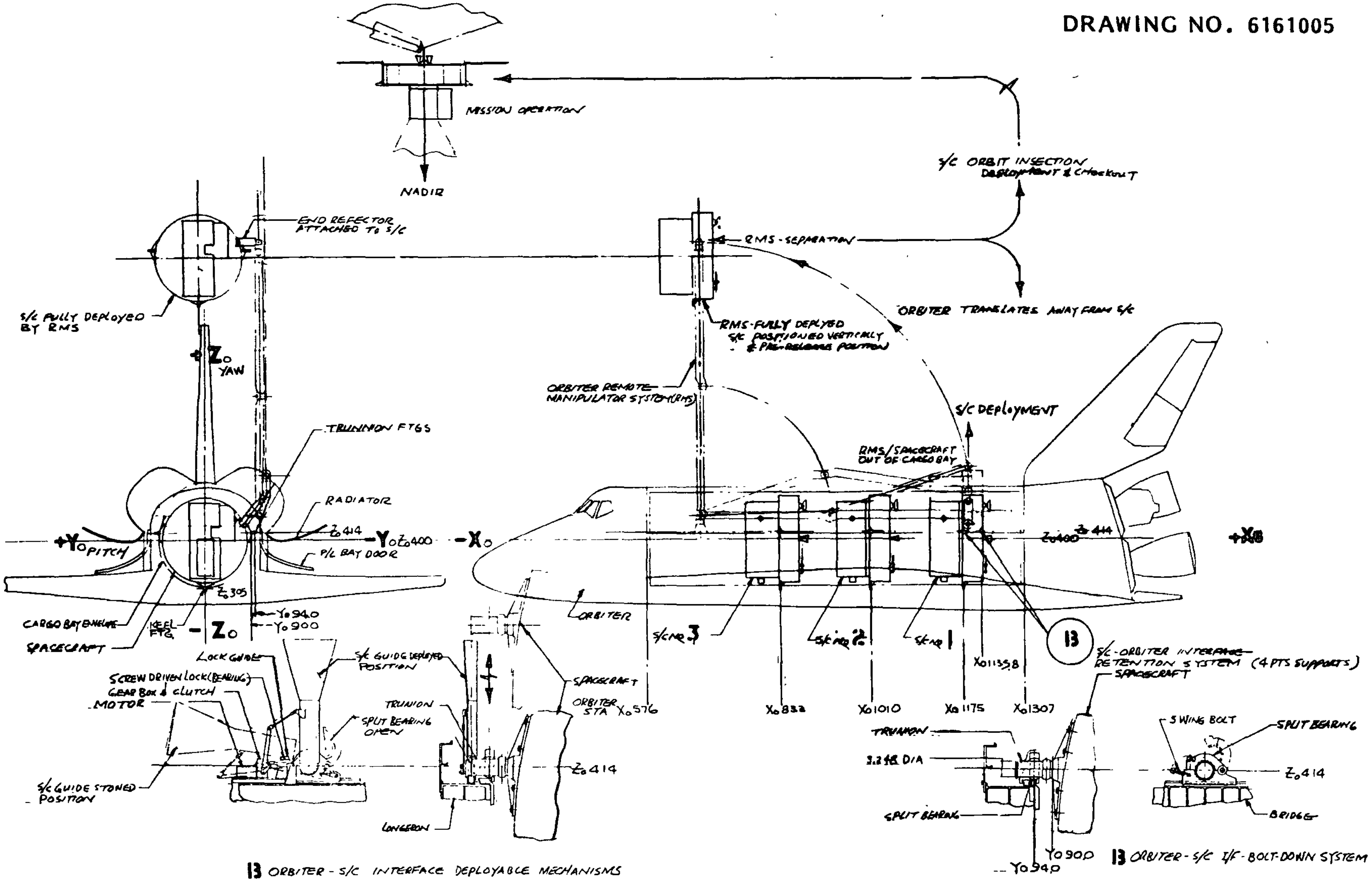
LAUNCH AND DEPLOYMENT CONCEPT
THREE SPACECRAFT LAUNCH

DRAWING NO. 6161005



13 ORBITER - S/C INTERFACE DEPLOYABLE MECHANISMS

13 ORBITER - S/C I/F - BOLT-DOWN SYSTEM

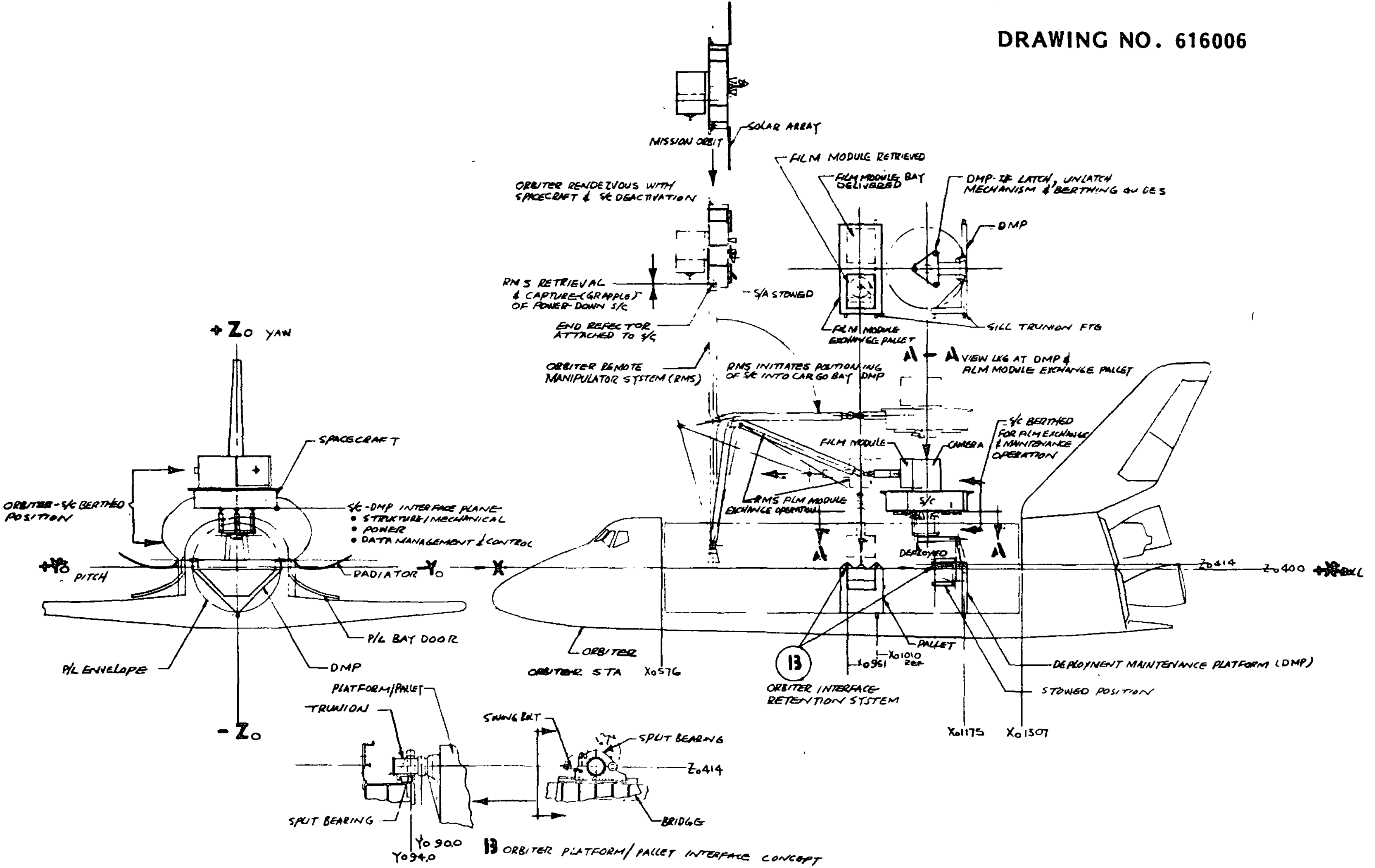
FREE FLYER ORBITAL MAINTENANCE, FILM MODULE EXCHANGE AND REPLACEMENT CONCEPT

Orbital Maintenance, Film Module Exchange and Replacement Concept. Drawing 6161006 presents the film module exchange and replacement scheme. Onboard of the orbiter is a deployment maintenance platform (DMP) and a film module exchange pallet which contain the new film module for replacement. To retrieve the free flyer camera spacecraft for film exchange in zero-g environment, the shuttle manipulator is used. The end effector rigidly mates with the spacecraft receptor. The free flyer can then be moved to various positions by the manipulator and placed on top of the DMP and latched in position for film module exchange operation. Drawing 6161006 shows the spacecraft supported by DMP as film modules are replaced by the shuttle manipulator. The modules could also be exchanged by a suited crewman if EVA is used.

The DMP is being developed by LMSC for the Space Telescope Program. Other positioning platforms developed by NASA GSFC for the multi-modular spacecraft program will be flown very early in the STS flight. This will provide operational experience and a totally flight qualified unit. Use of the DMP approach for exchanging the film package also provides the capability for the RMS (after S/C capture) to berth the spacecraft to the DMP and, if desired, rotates it back down into the payload bay for earth return. Thus, contingency retrieval and earth return of the spacecraft are ancillary features of the basic deployment concept selected for orbital maintenance and film module exchange in space.

ORBITAL MAINTENANCE FILM MODULE EXCHANGE AND REPLACEMENT CONCEPT

DRAWING NO. 616006

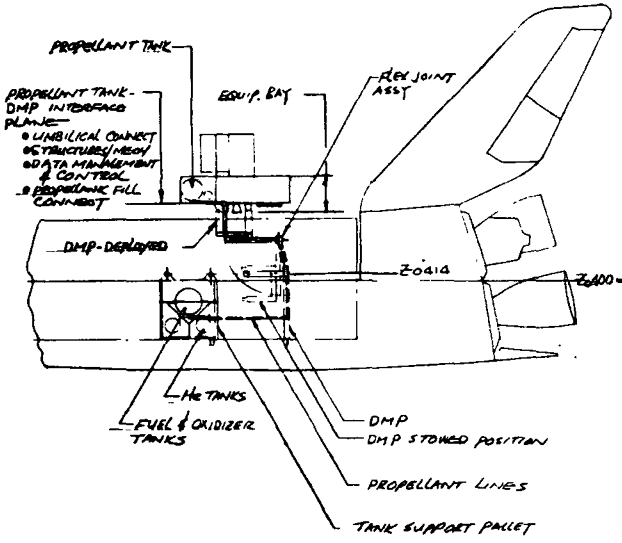


FREE FLYER PROPELLANT REFILLING AND REPLACEMENT CONCEPT

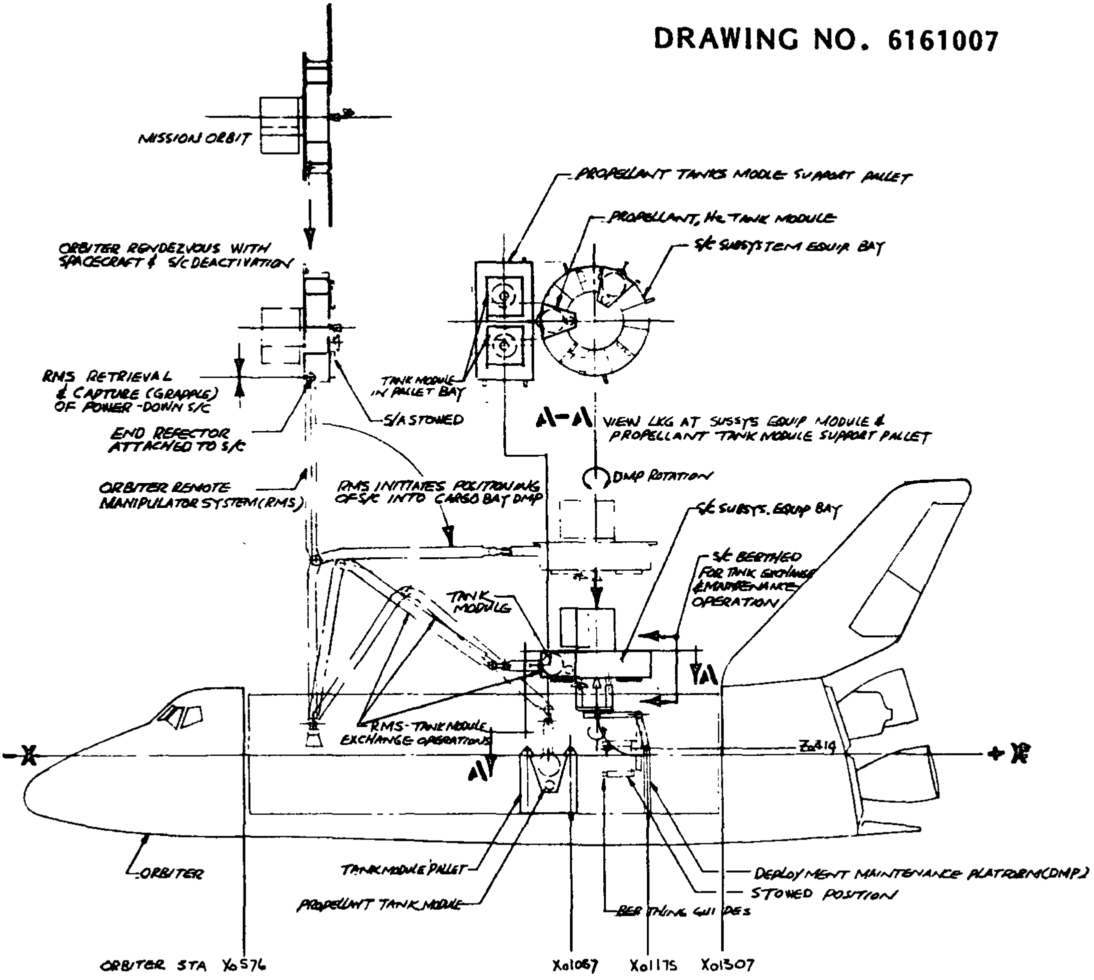
Propellant Refilling and Replacement Concept. Two preliminary refueling concepts have been developed. (1) The propellant module exchange concept which is similar to the film module exchange described previously, and (2) the propellant transfer concept in which propellants (fuel, oxidizer and pressurization gas) are delivered via shuttle orbiter. Interim free flyer will rendezvous with the DMP, propellant transfer remote connectors will be connected to the spacecraft propellant tank system for refilling operation. Upon completion of the operation the RMS is then used to lift the spacecraft off of the DMP. Drawing 6161007 illustrates the basic propellant refilling and module exchange concept.

FREE FLYER PROPELLANT REFILLING AND REPLACEMENT CONCEPT

DRAWING NO. 6161007



• PROPELLANT TRANSFER CONCEPT



• PROPELLANT TANK MODULE EXCHANGE CONCEPT

APPENDIX B

MC & G CONSIDERATIONS

MC & G CONSIDERATIONS

Introduction.

Two general types of questions require investigation. First, it appears appropriate to obtain a better insight and understanding of the MC&G requirements as a function of time over the next ten years. Second, a preliminary approach to meet the requirements should be formulated with enough design to allow an error analysis to be conducted. Analysis at this stage is indicated because of the extremely high accuracies being sought. Specifically the requirement for angular accuracies of the order of 1 to 2 arc seconds (5 to 10 μrads) overall means that many error sources and calibration schemes must be considered. Part of the overall synthesis must include concepts for calibration since in most areas integrity of (initial) alignments will not be compatible with required performance. Stability of subsystems and overall installation will be of prime concern.

In support of that objective, a preliminary system synthesis and analysis is outlined in the following pages and charts, followed by several key questions needing further resolution.

MC & G SCENE LOCATION ACCURACY INPUTS

From various sources it has been concluded that MC&G requirements call for earth point location accuracy of the order of 25 ft., 1 sigma, in all three directions. There has been some indication that location accuracy as good at 15 ft. would be desirable. Since the sources for these requirements have not been verified - in terms of the justification for the requirements/desirements - our approach has been to treat these accuracies as ballpark requirements and to identify the capabilities available to provide the approximate level of performance. Roughly speaking, it appears that 1986 State-of-the-art (SOTA) technology will come close to providing the 25 ft. location accuracy in realtime (on the primary record) and the 15 ft. accuracy on the ground in a post-pass (non-realtime) mode.

In order to obtain more confidence in a system for achieving the necessary performance and to obtain a better assessment of the expected performance, additional studies are needed to address the specific system requirements, i.e., performances stated in this preliminary analysis have been derived by use of engineering judgement taken from results gained from other studies with similar but not identical requirements.

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MC & G SCENE LOCATION ACCURACY INPUTS

MC&G REQUIREMENTS PER SP DOCUMENT

- FOR POINT POSITION DATA BASES (PPDB)
  - 36 FT HORIZONTAL
  - 39 FT VERTICAL
- FOR TERRAIN CONTOUR MATCHING (TERCOM)
  - 75 FT HORIZONTAL
  - 23 FT VERTICAL

MC & G LOCATION ACCURACY

The approach taken to identify a system concept for obtaining the desired performance was to establish a nominal error for the elements of the general type of system indicated and to see if an implementation were available within the SOTA.

Two basic elements of information are necessary to establish the location of earth points on satellite imagery. They are a knowledge of the satellite position in an earth fixed coordinate system and a knowledge of the camera optical axis (line of sight) orientation in the same earth fixed coordinate system. Because of the extreme accuracy required, the only feasible way of obtaining the LOS orientation is to measure vehicle or camera orientation relative to the stars and to tie that to an earth fixed coordinate system by means of an accurate ephemeris. To accomplish this in real time, especially to provide target location information on the primary record requires that the ephemeris be available onboard the satellite in real time. This suggests the use of the NAVSTAR GPS for satellite ephemeris determination as the only practical implementation.

With a system of satellite mounted star sensors for attitude and the GPS for ephemeris the following error sources must be considered.

- Satellite Position (ephemeris) uncertainty
- Star sensor uncertainty
- Star sensor - camera boresight alignment/calibration
- Satellite angular rate uncertainty

The allocations in the chart appear reasonable. The driver is probably the GPS capability. It is expected that the capability of this system, especially, will improve between now and the late eighties. Hence, three different budgets are shown as a function of time. The goal may only be achievable with the use of post pass (non-real time) techniques.

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MC & G LOCATION ACCURACY

ERROR BUDGET

		1σ POSITION UNCERTAINTY			
			LINEAR (FT) AT 167 NM		
NO.	SOURCE	ANGULAR (μRAD)	1984	1986	GOAL
1	GPS (REAL TIME)	NA	50	15	10
2	STAR SENSOR	10	15	10	5
3	STAR SENSOR/CAMERA LOS UNCERTAINTY	10	15	10	5
4	VEHICLE RATE UNCERTAINTY	10	15	10	5
5	GROUND CALIBRATION POINTS	–	15	10	5
	TOTAL (RSS)	NA	60	25	15

GPS CAPABILITY

The accuracy of the GPS for low altitude satellites (150 nm to 300 nm) has been analyzed by LMSC in the course of two different studies over the last four years. As a consequence of the low drag uncertainties and in light of fairly good geometry for orbits with inclinations less than 60 deg., studies showed that for User Equivalent Range Errors (UERE) (in pseudo range) of the order of 5 ft., position uncertainties of about 15 ft. could be achieved about 50% of the time. For 90% of the time, position uncertainties of less than 25 ft. should be achieved. These uncertainties are for the all-up 24 satellite GPS network. This GPS net is currently expected to be full by 1986. Prior to that time satellite users could expect to realize use of the system at degraded accuracy levels. Use would still be world wide because of the fact of the user being in orbit. GPS program plans call for a constellation of six satellites to be maintained from 1979 until about 1983 when the number will be increased from six to 24. Studies show that with six or more GPS satellites, low altitude satellite users with nominal on-board ephemeris computation/prediction capability will be able to generate their own ephemeris on-board to about 50 ft. This is achieved by using GPS information on an as-available basis to update the continuously generated ephemeris. The geometry and timing is such that typical maximum dark time will be about 30 minutes. (Dark time is that time during which the user satellite is blocked by the earth from receiving any of the six GPS satellites.)

The above performance is predicated on GPS achieving the indicated 5 ft. UERE. This seems a good possibility at this time because the four GPS satellites now in operation appear to be giving lower uncertainties in pseudo range than was expected.

Space qualified user equipment is now under development by APL and Magnavox. It is being planned for an experiment on Landsat and on P-467. The equipment is being developed under the direction of DMA with APL as the integration contractor. Preliminary weight estimates are as follows:

Receiver Processor Assembly (RPA) (internally redundant) .... (Compatible with Landsat)	38.0 lbs.
Oscillator	2.4 lbs.
Pre AMP	5.1 lbs.
Antenna and Harness	4.5 lbs.
Subtotal	50.0 lbs.
P-467 Interface & Storage Box	55.0 lbs.

These weights are for a set of space-borne equipment designed primarily for an experiment/evaluation operation. As such, they could probably be reduced by about a factor of two for an operational system. The interface and storage unit now envisioned for the P-467 experiment would certainly not be required. It seems not unreasonable to expect that an internally redundant system weighting 20 lbs. and requiring 20 watts could ultimately be implemented.

GPS CAPABILITY (1986 ⟶)

- REAL TIME
  - ACCURACY – 15 FT 1σ
  - IMPLEMENTATION
    - 125 LB, 25 WATTS
    - KNOWLEDGE AVAILABLE ONBOARD
    - READOUT ON PRIMARY RECORD
- POST PASS (BACK FIT EPHEMERIS)
  - ACCURACY – 10 FT 1σ
  - IMPLEMENTATION
    - 100 LB, 20 WATTS GPS
    - 2 kHz REAL TIME LINK
    - GROUND COMPUTATION
    - GPS CLOCK ON PRIMARY RECORD

STAR SENSOR

Two different concepts have been discussed for the star sensors required to provide the precision attitude reference. One is to tie the star sensor to the camera optical axis, e.g., by means of using the back surface of the camera panning device for an element of the star sensor. This concept has the advantage of eliminating the need for a precision resolver between the camera instantaneous LOS and the LOS to the stars. However, preliminary mechanization concepts have been thwarted to a large degree by clear field of view/access problems. Both vehicle structural blocking and the problems posed by the sun and/or sun shield have mitigated against this option in all implementations considered to date. This leaves as the only identified alternative a system in which a minimum of two star sensors are mounted fixed to the camera frame and pointing generally upwards but separated by about 90 deg. To acquire knowledge of the camera instantaneous LOS relative to the coordinate system defined by the star sensors requires a precision resolver on the camera panning mechanism. Primary candidate for this is the 12 inch Inductosyn which promises resolution of 2 to 5 μrads. Note that for a system which pans at about 20 deg/sec (72,000 arc sec/sec) 1.5 megabit/sec readout bandwidth is required (since 1 arc sec resolution requires a 20 bit word).

The star sensor, to support this level of performance, would need to be able to get good signal-to-noise from about 6th magnitude stars.

STAR SENSOR

- FOCAL PLANE (CCD) ALTERNATIVES
  - MOSAIC FOCAL PLANE
  - FENCE (NON DENSE) FOCAL PLANE
- 4 IN. OBJECTIVE } 10 μRAD
- 6TH M_V STARS }
- NO REFRIGERATION
- AT LEAST ONE STAR IN FOV
- 4° DIAM FOV
- 1 SEC UPDATE
- ON PRIMARY RECORD
- SUN SHIELD – MAJOR CONSIDERATION
- GOAL – 5 μRAD (STABILITY, CALIBRATION)

VEHICLE RATE UNCERTAINTY

The requirement on the star sensor is that it have a star in its field-of-view(FOV) at all times. This stems from a desire to implement the system without the use of precision gyros. Although a detailed trade study should be made, a preliminary feel and sizing can be obtained by assuming use of sixth magnitude stars. Their average density is one star per 14 deg^2. Thus, a 4 deg. diameter FOV would give a good probability (about 90%) of a star in the field at all times. To get good S/N on sixth magnitude stars requires an aperture of about 4 inches. These are reasonable requirements. Roughly speaking the size of the star catalog required would be 90 x 17 x 7 or about 10^4 stars if the star catalog were to be updated once per week. This is also a reasonable number. The trade off here would be between more (dimmer) stars and either a larger storage or more frequent update along with smaller sensor FOV but larger optics, versus fewer (but brighter) stars, smaller optics and wider FOV. Other studies for similar applications have identified a system based on sixth magnitude stars as a good compromise.

Previous studies and implementations have shown that the sun shield for the sensor is a major concern. The fact that best illumination for camera operation occurs when the sun is "behind" the camera and that one must also see stars that are to a first approximation "behind the camera" points out the basic problem. It is compounded by the fact that many different sun angles may be experienced. This results in a constraint on the star sensor placement geometry that requires either extensive sun shield to allow the sensor to look as close as 20 deg. to the sun, the use of three or more sensors, or the imposition of vehicle maneuvers to avoid the sun in the star sensors FOV. The best choice depends on specifics of the vehicle and orbits.

Another detailed design consideration for the star sensor is the type of focal plane. Conceptually the best solution is a dense focal plane with pixels about 20 to 30 μ rads on a side. With such a configuration one is able to get good derived rate information whenever there is a star in the FOV. However, this would require about 10^7 pixels which is a driving manufacturing and cost problem for the focal plane. Alternatives are to use larger pixels and/or a less than fully dense focal plane. Since vehicle (and hence, star sensor) rotation is predominantly around a single vehicle axis, i.e., pitch, it is possible to consider a focal plane consisting of a series of fences, like slits, that the stars would have to cross. (This is similar to the SPARS type approach.) However, this would then place more severe demands on the vehicle rotation, disturbance torque model in order to obtain derived rate to the required precision. Since uncertainty torques are small, however, this scheme offers promise. A detailed analysis should be made.

A major objective here is to avoid the necessity for precision rate gyros as part of the precision attitude determination system. Both reliability and cost are factors in this choice.

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VEHICLE RATE UNCERTAINTY

- DERIVED RATE (NO PRECISION GYROS)
- REQUIRES MODELING INCLUDING VEHICLE INERTIA AND DISTURBING TORQUES (SOLAR, CAMERA PAN, CONTROL)
- REQUIRES STAR IN SENSOR FOV FOR BEST PERFORMANCE
- 10 μRAD NOMINAL, 5 μRAD GOAL (BETTER MODEL AND/OR MORE STARS)

STAR SENSOR CAMERA RELATIVE BORESIGHT

In order to obtain the angular accuracy required for the MC&G function it will be necessary to perform on-board in-orbit calibration of the total attitude determination system. This stems from two main factors. One is the inherent difficulty of ascertaining the location of the optical axis or LOS of the star sensors and the camera to the order of a few μ rads as they are mounted in the vehicle. The other is the shift in initial alignment due to launch and as a consequence of thermal cycling while in orbit. The fact that the second problem exists, mitigates against trying to solve the first. The only way to deal with the second problem is to provide for on-board calibration. The standard procedure here is to point the camera at the stars and to take simultaneous looks at the stars with the camera and with the star sensors. For the accuracies desired it may be necessary to calibrate several times per day, perhaps even once per orbit. And since the thermal deflections will be a function of sun angle, it will be desirable to perform the calibrations at latitudes similar to those of the targets of interest. This could mean calibration runs on the orbits before and after a series of operational runs.

STAR SENSOR CAMERA RELATIVE BORESIGHT

- POINT CAMERA AT STARS FOR SENSOR-CAMERA CALIBRATION
- THERMAL INTEGRITY IS MAIN CONSIDERATION IN FREQUENCY OF CALIBRATION
- CAMERA POSITION RESOLVERS (INDUCTOSYNS)
- GOALS – 5 μRAD

GROUND CALIBRATION

One remaining error source of potential significance is the deviation of the angle between the camera and star sensor optical axis from the condition where the camera is looking at the stars (where primary calibration is performed) and the condition where the camera is pointing at the earth. To check on this difference it may be necessary to use ground truth targets. It may suffice here to use only calibration points within the CONUS. However, if remote ground truth checking is required, this may be aided by using GPS receivers in the general vicinity of the target area or simply by checking location of targets whose position is already well established in the WGS 72 coordinate system.

GROUND CALIBRATION

- BOOTSTRAP TECHNIQUES
  - TIE KNOWN TARGETS TO WGS 72
  - ITERATE TARGET POSITION IN GPS GRID
- USE GPS REMOTE RECEIVERS TO GET BENCH MARKS AT REMOTE LOCATIONS
- GOAL – 5 FT

QUESTIONS NEEDING MORE RESOLUTION

To summarize, the questions posed that need further resolution are:

(1) What are the MC&G needs and how will the data be used versus time compared to the potential capability for meeting these needs? It appears that something between 15 and 25 ft. can be achieved. How much will it cost to provide a system giving 15 ft. vs. one giving 25 ft? How much will it cost to provide real-time target location on the primary record vs. providing it post flight?

(2) A fence type focal plane for the star sensor appears attractive. Can the derived rate requirements be met with that implementation? Does the saving in number of pixels compete favorable with the potential added complexity?

(3) The sun shield geometry is difficult at best. Does an additional sensor plus the redundancy implicit in that implementation result in a more cost effective system than one with extensive sun shield design and/or arrangement?

(4) The thermal integrity of the camera-star sensor alignment will be of major concern. What design techniques will minimize thermal deviations? How frequently will calibration be required?

QUESTIONS NEEDING MORE RESOLUTION

1. CAPABILITY VS TIME VS NEEDS
2. REAL TIME VS POST PASS KNOWLEDGE
3. STAR SENSOR DETAILED TRADES (FOCAL PLANE)
4. SUN SHIELD CONSTRAINTS/LIMITATIONS
5. THERMAL INTEGRITY –
    - CAMERA/STAR SENSOR BORESIGHT

APPENDIX C

WEATHER DATA

WEATHER DATA

Introduction

This appendix provides data on several aspects of weather statistics which affect the analysis of quantity performance of the SCS. Most of the data provided is based on information which was not available at the time of preparation of Volume I. These data confirm the validity of the SCS study quantity performance analysis in all aspects which affect the study conclusions. They show that although the absolute performance predictions may be somewhat optimistic, the relative performance established for the systems studied is valid even though factors of temporal correlation and weather prediction errors were not taken into account.

The following subject areas are addressed:

1. Ten day weather averages of PROBLOOK and PROBCLEAR (for 60% threshold) obtained from the Air Weather Service.
2. Mission-to-mission CFDs* (cumulative frequency distribution) for PROBLOOK, 20 day and 60 day missions
    a. Full range CFDs; used to confirm that appropriate weather levels were used in the Volume I analysis
    b. Low range CFDs; used to compare variations, under poor weather conditions, between 20 day and 60 day missions.
3. Mission-to-mission CFDs for PROBCLEAR; used to help confirm the assumption that a 60% threshold can produce 80% cloud-free imagery.
4. Typical bias for estimation of cloud-free take; shows relation between verified cloud data (at time of pass) to confirmed data (based on resulting imagery) to further support 80% take with 60% threshold.
5. Typical weather prediction statistics and impact on performance prediction; used to estimate the magnitude and effects of the inaccuracy in performance estimates due to neglecting weather prediction errors in the Volume I analysis.

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*CFD(x) is the probability that PROBLOOK (or PROBCLEAR) is between 0 and x.

TEN DAY WEATHER AVERAGES, 60% THRESHOLD

Each of the following four charts provide 4 years of data showing "PROBLOOK" and "PROBCLEAR," based on ten day averages for 60% threshold in the vicinity of each of four points in dense target areas. The PROBLOOK values are the frequency with which clearness (1-cloud cover) exceeded 60% at 15 grid points (3 by 5 pattern on 50 nmi centers) centered at each of the four points. "PROBCLEAR" is the weighted average value of clearness considering only those points which exceeded the 60% threshold.

The four points for which data are shown are:

Point #1: 50.5°N, 40.5°E. (Western USSR)
Point #2: 25°N, 110°E. (Southern China)
Point #3: 50°N, 15°E. (Europe)
Point #4: 55.7°N, 37.6°E. (Moscow)

These data were provided by the Air Weather Service at our request. They have been analyzed to estimate the frequency distributions of PROBLOOK and PROBCLEAR for 20 day and 60 day missions as displayed in subsequent charts.

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TEN DAY WEATHER AVERAGES—60% THRESHOLD—POINT #1 (WESTERN USSR)

		1972				1973				1974				1975			
		QTR				QTR				QTR				QTR			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PROBLOOK TEN DAY PERIOD #	1	.293	.040	.100	.113	.353	.547	.240	.560	.607	.120	.247	.513	.147	.540	.213	.320
	2	.600	.733	.740	.227	.347	.300	.353	.253	.680	.153	.120	.560	.107	.374	.413	.180
	3	.547	.247	.980	.167	.647	.133	.260	.040	.120	.013	.373	.227	-0-	.353	.333	.433
	4	.533	.340	.787	.053	.040	.373	.480	-0-	.013	.153	.327	.027	.360	.527	.280	.360
	5	.627	.560	.473	.067	.060	.387	.100	.080	-0-	.287	.493	.087	.133	.513	.300	.380
	6	.360	.607	.887	.020	-0-	-0-	.233	.093	.453	.126	.673	-0-	.213	.415	.473	.113
	7	.840	.553	.393	.080	.333	.327	.273	.147	.433	.333	.567	.020	-0-	.453	.347	.020
	8	.813	.380	.467	-0-	.133	-0-	.127	.167	.153	.180	.227	.147	.353	.540	.240	.147
	9	.173	.613	.233	.007	.373	.040	.340	.067	.153	.107	.440	.207	.280	.520	.727	.207
PROBCLEAR TEN DAY PERIOD #	1	.822	.717	.807	.802	.910	.873	.694	.849	.918	.799	.806	.786	.784	.888	.807	.786
	2	.896	.869	.875	.889	.934	.826	.789	.847	.892	.793	.672	.901	.912	.840	.819	.834
	3	.854	.853	.905	.720	.958	.740	.729	.667	.807	.675	.768	.766	-0-	.944	.806	.910
	4	.854	.832	.863	.810	.742	.779	.795	-0-	.775	.748	.789	.750	.800	.880	.724	.785
	5	.842	.790	.802	.770	.809	.799	.687	.750	-0-	.803	.789	.878	.735	.803	.827	.845
	6	.818	.826	.941	.733	-0-	-0-	.736	.739	.857	.691	.864	-0-	.788	.801	.888	.753
	7	.933	.770	.796	.721	.877	.799	.794	.775	.831	.764	.886	.683	-0-	.835	.893	.683
	8	.923	.761	.828	-0-	.814	-0-	.733	.884	.799	.757	.863	.748	.921	.848	.853	.748
	9	.791	.805	.750	.700	.855	.608	.835	.874	.739	.647	.778	.783	.865	.877	.913	.783

TEN DAY WEATHER AVERAGES—60% THRESHOLD—POINT #2 (SOUTHERN CHINA)

		1972				1973				1974				1975			
		QTR				QTR				QTR				QTR			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PROBLOOK TEN DAY PERIOD #	1	.200	.013	-0-	.267	.100	.087	.133	.233	.780	.107	-0-	.247	.100	.100	.033	.160
	2	.147	.033	.107	.060	.093	.027	.073	.447	.013	.087	-0-	.220	.060	.113	.067	.040
	3	.600	.113	.047	.033	.067	.067	-0-	.093	.013	.233	.013	.380	.233	.080	.040	.173
	4	.200	.093	.127	.333	.020	-0-	.093	.427	.020	.007	.020	.247	.013	-0-	.013	.360
	5	.387	.027	.153	.067	.013	-0-	.067	.267	.367	.013	.013	.087	-0-	-0-	.180	.160
	6	.120	.074	.353	.093	.320	.007	.053	.267	.313	.074	.227	.520	.133	.044	.160	.487
	7	-0-	.360	.040	.307	.007	.020	-0-	.780	-0-	.153	.180	.187	-0-	-0-	.293	.187
	8	-0-	.267	.253	.300	-0-	-0-	.007	.507	.247	.007	.420	.013	.227	-0-	.100	.227
	9	.360	.040	.033	-0-	.167	.013	.167	.773	.207	-0-	.107	.040	.020	-0-	.187	.807
PROBCLEAR TEN DAY PERIOD #	1	.979	.675	-0-	.913	.922	.806	.667	.680	.973	.934	-0-	.670	.777	.909	.630	.652
	2	.764	.620	.641	.694	.686	.762	.673	.822	.650	.723	-0-	.803	.761	.934	.685	.683
	3	.910	.729	.657	.650	.740	.670	-0-	.711	.700	.777	.650	.876	.897	.833	.633	.783
	4	.872	.679	.674	.759	.667	-0-	.625	.788	.850	.700	.600	.785	.725	-0-	.625	.785
	5	.784	.675	.676	.620	.775	-0-	.655	.828	.891	.600	.600	.723	-0-	-0-	.711	.767
	6	.817	.695	.732	.902	.812	.700	.644	.900	.892	.660	.728	.925	.798	.725	.674	.823
	7	-0-	.782	.658	.955	.700	.650	-0-	.889	-0-	.717	.663	.913	-0-	-0-	.692	.798
	8	-0-	.698	.679	.914	-0-	-0-	.600	.899	.861	.600	.669	.700	.829	-0-	.677	.821
	9	.901	.633	.660	-0-	.823	.600	.668	.930	.822	-0-	.650	.708	.700	-0-	.646	.916

TEN DAY WEATHER AVERAGES –60% THRESHOLD–POINT #3 (EUROPE)

		1972				1973				1974				1975			
		QTR				QTR				QTR				QTR			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PROBLOOK TEN DAY PERIOD #	1	.080	-0-	.133	.193	.107	.007	.160	.487	.067	.587	.087	.093	.067	.040	.407	.033
	2	-0-	.020	.333	.333	.100	-0-	.040	.113	.060	.233	.013	.013	.147	.147	.080	.133
	3	.413	.080	.293	.140	.107	.113	-0-	.227	.160	090	.133	090	.100	.327	.087	.167
	4	.360	.240	.087	.120	.067	.167	.347	.540	.027	.087	.313	.093	.373	.153	.267	.193
	5	.067	.020	.440	.033	-0-	.140	.573	.013	.113	.187	.420	.120	.313	.320	.367	.040
	6	-0-	.163	.007	.007	-0-	.281	.507	.140	.220	.015	.053	.040	.487	.163	.253	.253
	7	.320	.300	.260	.220	.040	.053	.480	.060	.047	.067	.340	.007	.280	.087	.127	.040
	8	.053	.107	.087	.180	.140	.253	.513	.167	.067	.027	.367	.060	.067	.127	.307	.120
	9	-0-	.127	.107	.427	.520	.227	.080	.140	.440	.120	.107	.180	.100	.187	.227	.153
PROBCLEAR TEN DAY PERIOD #	1	.708	-0-	.675	.710	.916	.600	.665	.839	.774	.868	.696	.700	.799	.683	.742	.670
	2	-0-	.683	.708	.849	.865	-0-	.667	.671	.739	.779	.625	.675	.707	.825	.663	.723
	3	.875	.679	.701	.698	.781	.682	-0-	.816	.764	-0-	.710	-0-	.788	.856	.696	.758
	4	.846	.730	.669	.708	.848	.712	.786	.871	.775	.735	.730	.762	.869	.720	.762	.762
	5	.768	.617	.814	.630	-0-	.674	.823	.700	.753	.698	.792	.731	.820	.715	.711	.708
	6	-0-	.880	.600	.600	-0-	.737	.832	.705	.774	.725	.669	.667	.875	.795	.789	.804
	7	.729	.767	.733	.688	.650	.663	.810	.771	.729	.730	.791	.700	.792	.730	.775	.667
	8	.750	.672	.685	.774	.798	.714	.859	.847	.745	.637	.791	.744	.750	.676	.826	.731
	9	-0-	.708	.684	.773	.834	.712	.775	.849	.816	.733	.697	.844	.918	.718	.797	.890

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TEN DAY WEATHER AVERAGES—60% THRESHOLD—POINT #4 (MOSCOW)

		1972				1973				1974				1975			
		QTR				QTR				QTR				QTR			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
PROBLOOK TEN DAY PERIOD #	1	.373	.053	.253	.013	.173	.147	.233	.227	.433	.453	.173	.233	.087	.227	.253	.287
	2	.427	.460	.500	.200	.593	.180	.373	.093	.767	.093	.133	.200	.027	.080	.193	.160
	3	.587	.253	.567	.013	.433	.027	.047	.067	.013	.227	.367	.167	-0-	.453	.067	.187
	4	.440	.680	.587	.093	.127	.253	.267	.020	-0-	.153	-0-	.053	.100	.633	.193	.087
	5	.213	.246	.573	-0-	.193	.147	-0-	.033	-0-	-0-	.293	.053	.373	.647	.067	.273
	6	.827	.274	.520	-0-	.020	.126	.213	.060	.367	.067	.107	.013	.147	.052	.287	.280
	7	.693	.193	.247	-0-	.433	.500	.100	.200	.287	.013	.647	-0-	.107	.233	.233	.100
	8	.560	.293	.667	-0-	.307	.127	-0-	.173	.033	.327	.160	-0-	.307	.300	.060	.033
	9	.173	.367	.033	.053	.540	.173	.153	.047	.193	.133	.273	.013	.227	.487	.260	.133
PROBCLEAR TEN DAY PERIOD #	1	.839	.860	.745	.825	.883	.743	.727	.813	.837	.958	.779	.814	.673	.772	.830	.820
	2	.948	.839	.842	.804	.903	.796	.753	.750	.919	.791	.669	.849	.663	.822	.747	.869
	3	.929	.744	.754	.625	.926	.775	.636	.695	.650	.826	.786	.868	-0-	.866	.720	.879
	4	.843	.881	.762	.707	.876	.884	.718	.683	-0-	.720	-0-	.781	.767	.858	.774	.712
	5	.756	.740	.840	-0-	.817	.827	-0-	.640	-0-	-0-	.752	.781	.775	.798	.655	.885
	6	.858	.818	.888	-0-	.833	.828	.770	.738	.888	.778	.669	.700	.777	.786	.833	.818
	7	.862	.772	.755	-0-	.827	.710	.743	.792	.835	.600	.839	-0-	.756	.828	.767	.670
	8	.898	.753	.841	-0-	.829	.711	-0-	.830	.730	.794	.719	-0-	.890	.754	.700	.730
	9	.704	.709	.690	.706	.911	.688	.773	.834	.882	.754	.887	.650	.750	.765	.748	.774

PROBLOOK STATISTICS, 20 DAY AND 60 DAY MISSIONS

The following nine charts provide PROBLOOK statistics based on 4 years of data for 20 day and 60 day missions in the following groupings:

A.	4 charts:	Cumulative Frequency Distributions (CFD's)* of PROBLOOK for each of 4 points by quarter
B.	1 chart:	Mean and standard deviation of PROBLOOK distributions - all 4 points by quarter
C.	4 charts:	Low range of PROBLOOK CFD's, presented at expanded scale

From B it can be seen that values of PROBLOOK between .15 and .25 are quite common and could be considered typical for dense target regions. This confirms that appropriate weather levels were used for the quantity performance analyses summarized in Volume I.

From A and B it can be seen that some probability exists for PROBLOOK of less than 0.1. However, it is also apparent that for all four points and all four quarters PROBLOOKs of greater than 0.1 occur for both 20 day and 60 day missions. Furthermore, at each point there is at least one quarter for which PROBLOOK $\geq$ 0.1 occurs on 100% of the 60 day missions (CFD (0.1) = 0) and on over 80% of the 20 day missions (CFD (0.1) $\leq$ 0.2.)

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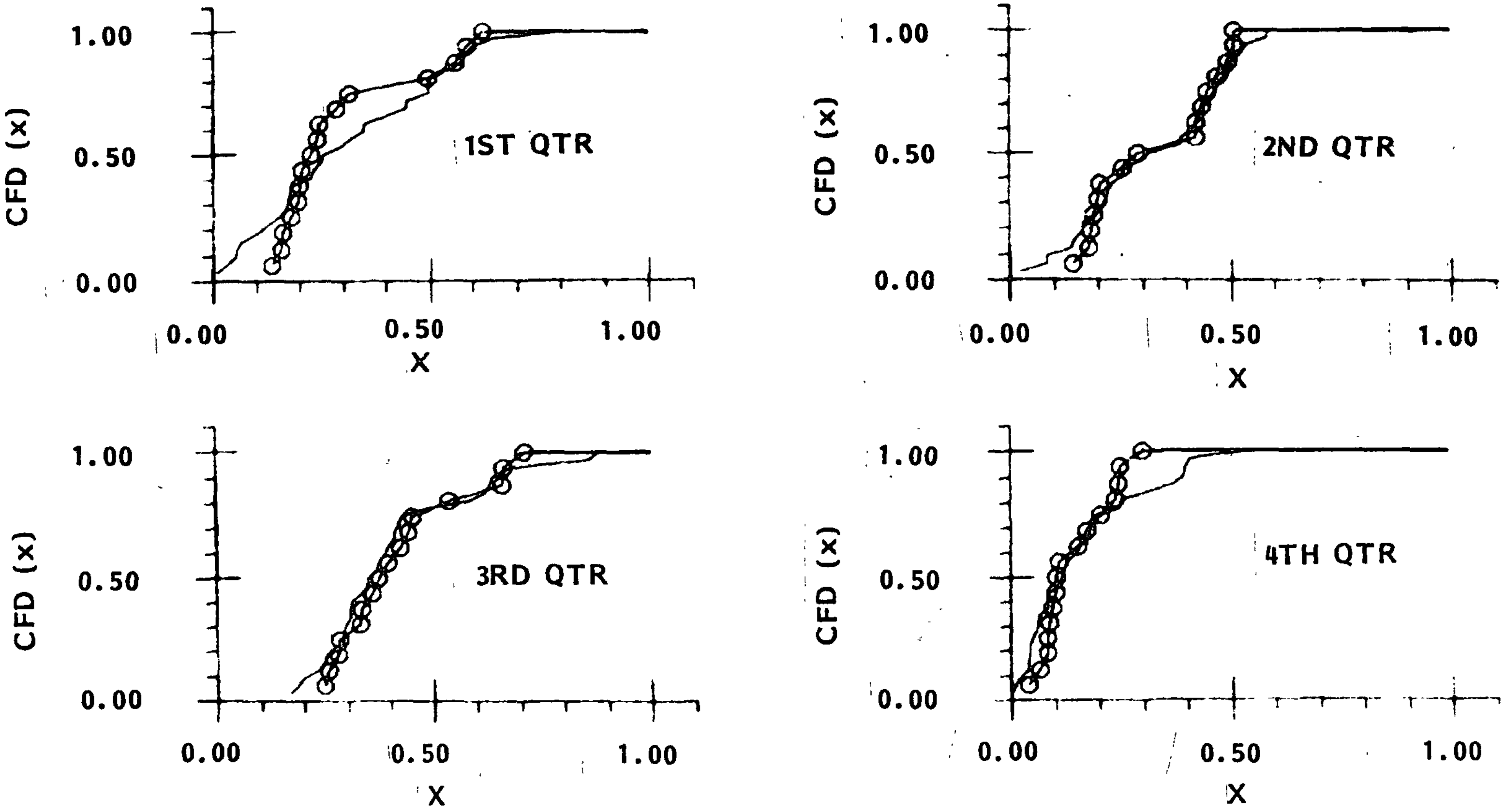
*CFD(x) is the probability that PROBLOOK is between 0 and x.

PROBLOOK—POINT #1 (50.5N,40.5E)

PROBLOOK CFDs* – 60% THRESHOLD

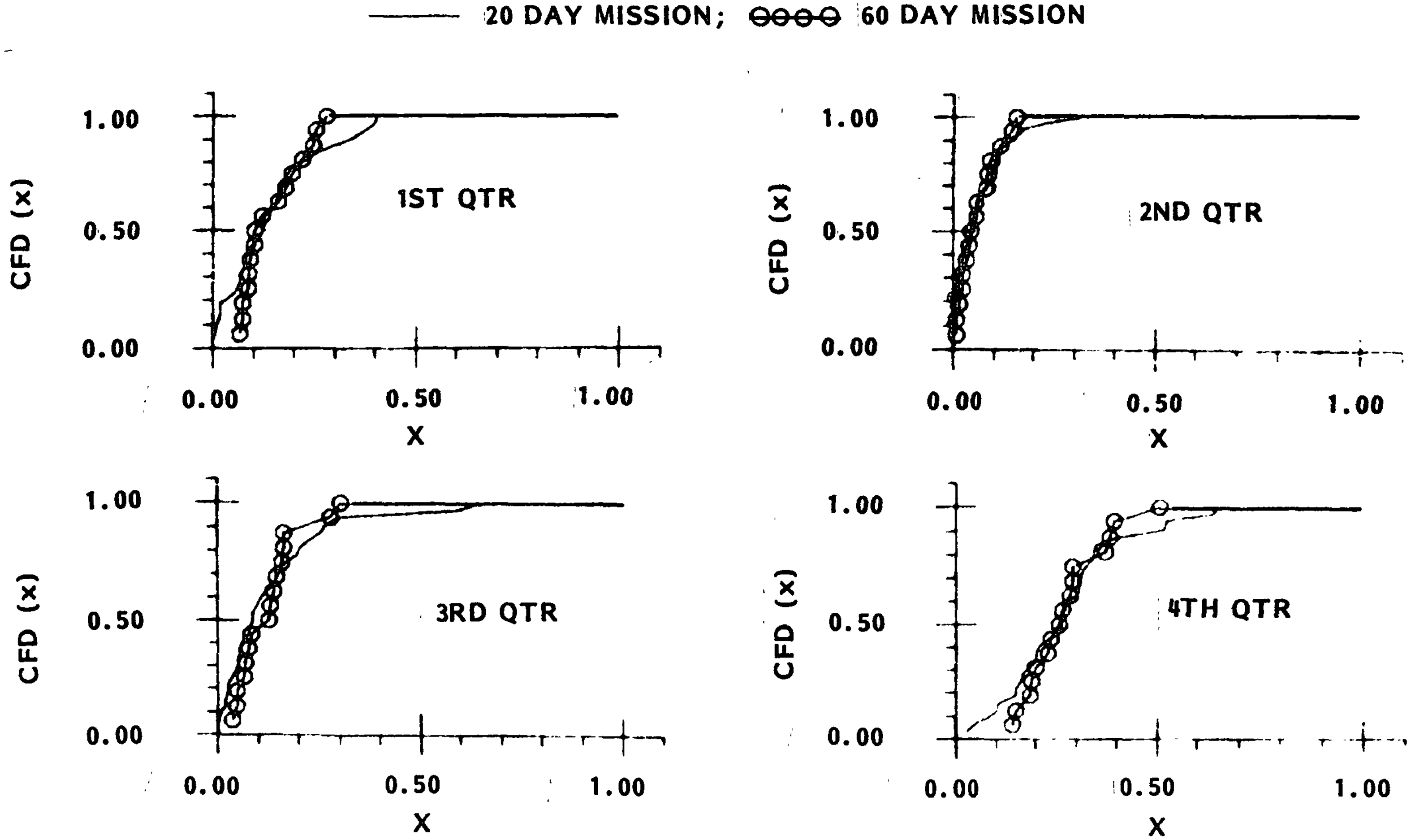
—— 20 DAY MISSION; ○○○○ 60 DAY MISSION



*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

PROBLOOK—POINT #2 (25N,110E)

PROBLOOK CFDs* – 60% THRESHOLD

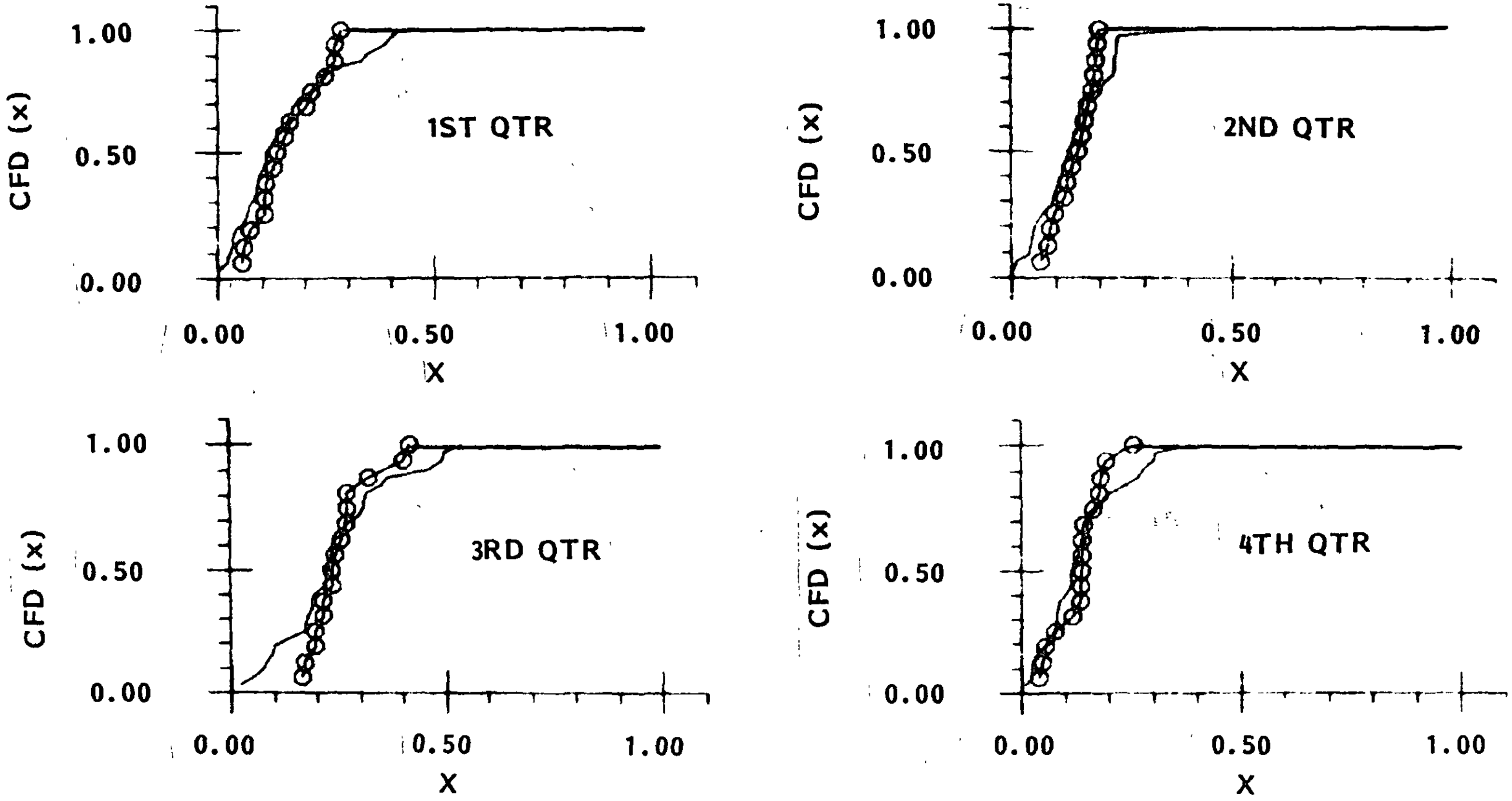


*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

PROBLOOK—POINT #3 (50N,15E)

PROBLOOK CFDs* – 60% THRESHOLD

—— 20 DAY MISSION; ΘΘΘΘ 60 DAY MISSION

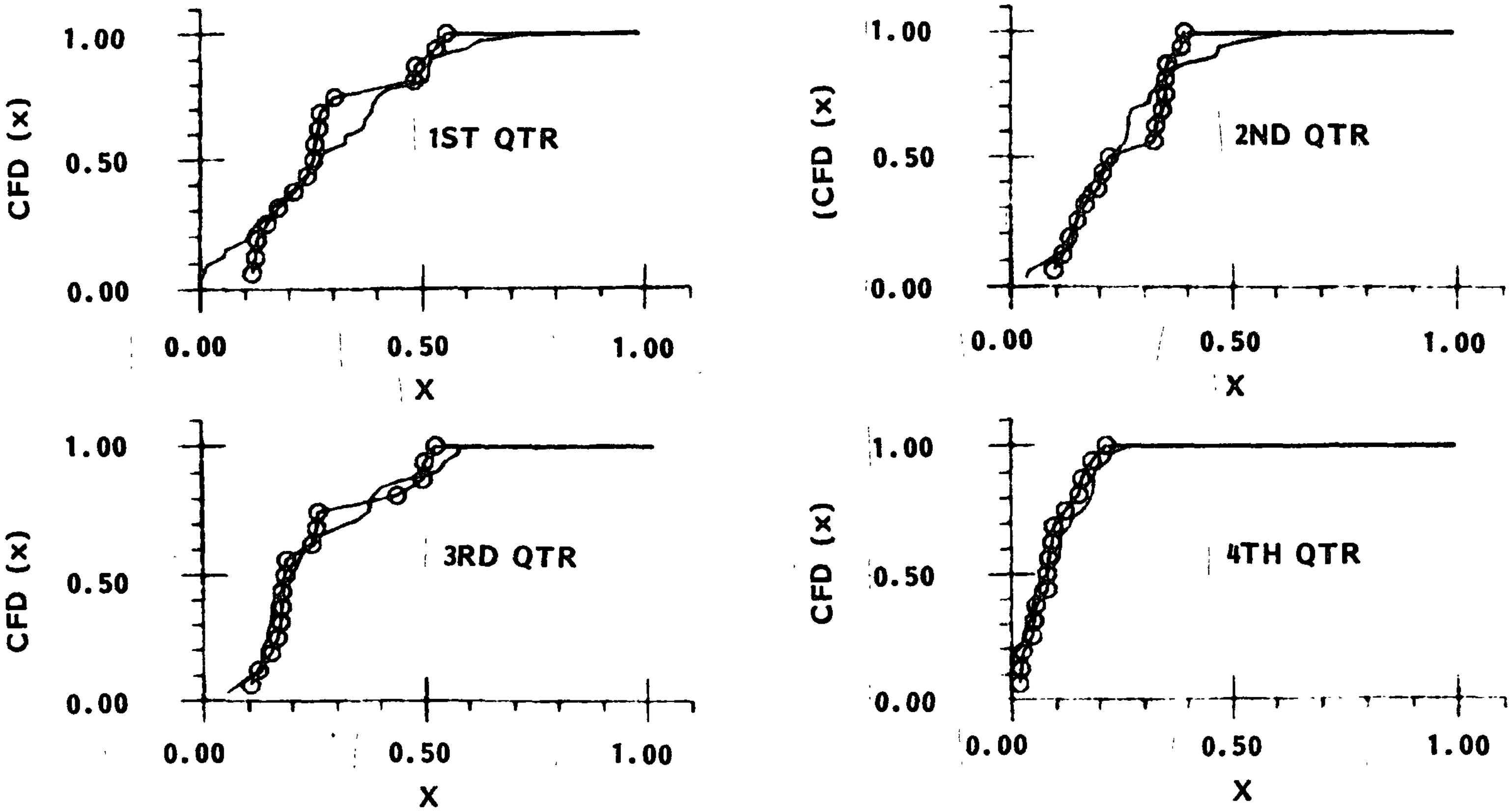


*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

PROBLOOK—POINT #4 (55.7N,37.6E)

PROBLOOK CFDs* – 60% THRESHOLD

—— 20 DAY MISSION; ⊖⊖⊖⊖ 60 DAY MISSION



*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

PROBLOOK MEAN AND STANDARD DEVIATION BY QUARTER, 60% THRESHOLD

POINT	MISSION DURATION DAYS	1st QTR		2nd QTR		3rd QTR		4th QTR	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
#1 Western USSR	10	.313	.243	.327	.204	.396	.220	.169	.160
	20	.315	.210	.329	.161	.406	.181	.159	.137
	60	.299	.166	.334	.140	.422	.150	.145	.079
#2 Southern China	10	.154	.180	.063	.082	.129	.183	.275	.212
	20	.143	.117	.065	.071	.135	.151	.270	.154
	60	.145	.072	.061	.047	.127	.079	.272	.099
#3 Europe	10	.156	.154	.144	.123	.233	.165	.145	.131
	20	.153	.117	.141	.087	.242	.130	.137	.092
	60	.160	.078	.145	.045	.255	.073	.133	.057
#4 Moscow	10	.294	.231	.252	.184	.253	.192	.099	.093
	20	.296	.197	.252	.141	.259	.154	.096	.078
	60	.283	.149	.256	.106	.261	.145	.092	.059

PROBLOOK STATISTICS, 20 DAY AND 60 DAY MISSIONS (CONT)

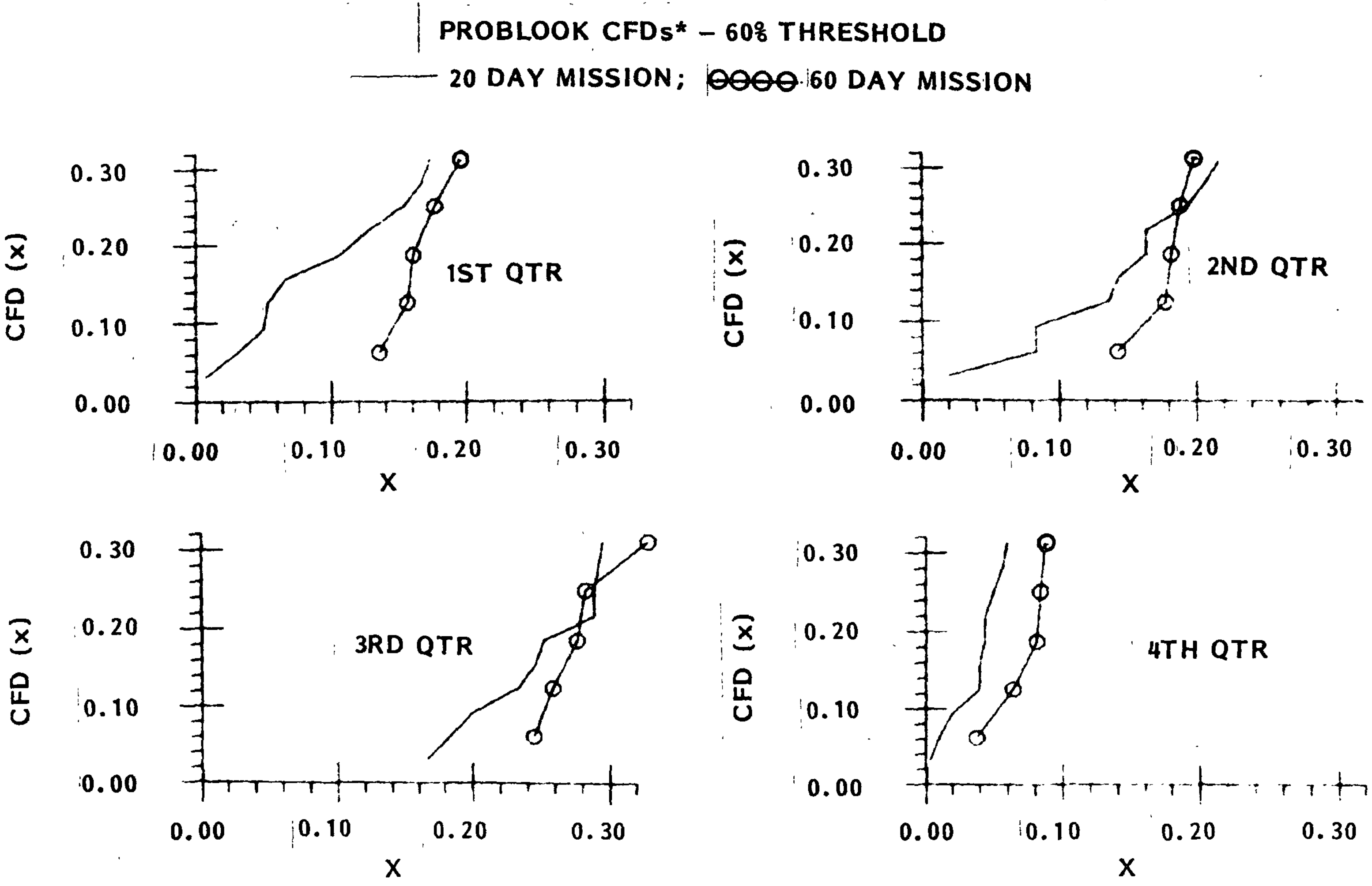
The Group C low range curves are particularly useful for comparing 20 day and 60 day mission effectiveness with respect to the effects of temporal correlation. As pointed out in Volume I, when the weather is poor, there can be 20 day periods in which the clearness never exceeds 60% (i.e., CFD(0) >0). Several examples of this situation can be seen on the low range curves.

To further compare the relative effectiveness of 20 day and 60 day missions, consider first that when PROBLOOK ≥0.1 there is a reasonable chance for successful imagery and chance of success increases with PROBLOOK. Now, if the criterion is applied that 80% of a mission in a given quarter should provide successful imagery in a given region (point), then one need only compare resulting PROBLOOKs at the CFD = 0.2 level for those 20 day and 60 day missions for which PROBLOOK exceeds 0.1. Under these conditions the data show three cases for which 20 day missions are inferior to 60 day missions. These cases and the corresponding PROBLOOK values for 60 day and 20 day missions are:

	P_{60}	P_{20}	$P_{60} - P_{20}$
Point No. 1, 1st Quarter:	0.160	0.108	0.052
Point No. 2, 4th Quarter:	0.185	0.148	0.037
Point No. 3, 3rd Quarter:	0.195	0.116	0.079

While these results indicate there is some advantage of 60 day missions over 20 day missions, which was not considered in Volume I, the magnitude of this advantage is not sufficient to invalidate the basic conclusion that the 20 day ETR pallet mission at 57° inclination is an attractive alternative. Furthermore, the variation of PROBLOOK between 20 day and 60 day missions are less than point-to-point and quarter-to-quarter variations (for equivalent CFDs) for a given type mission.

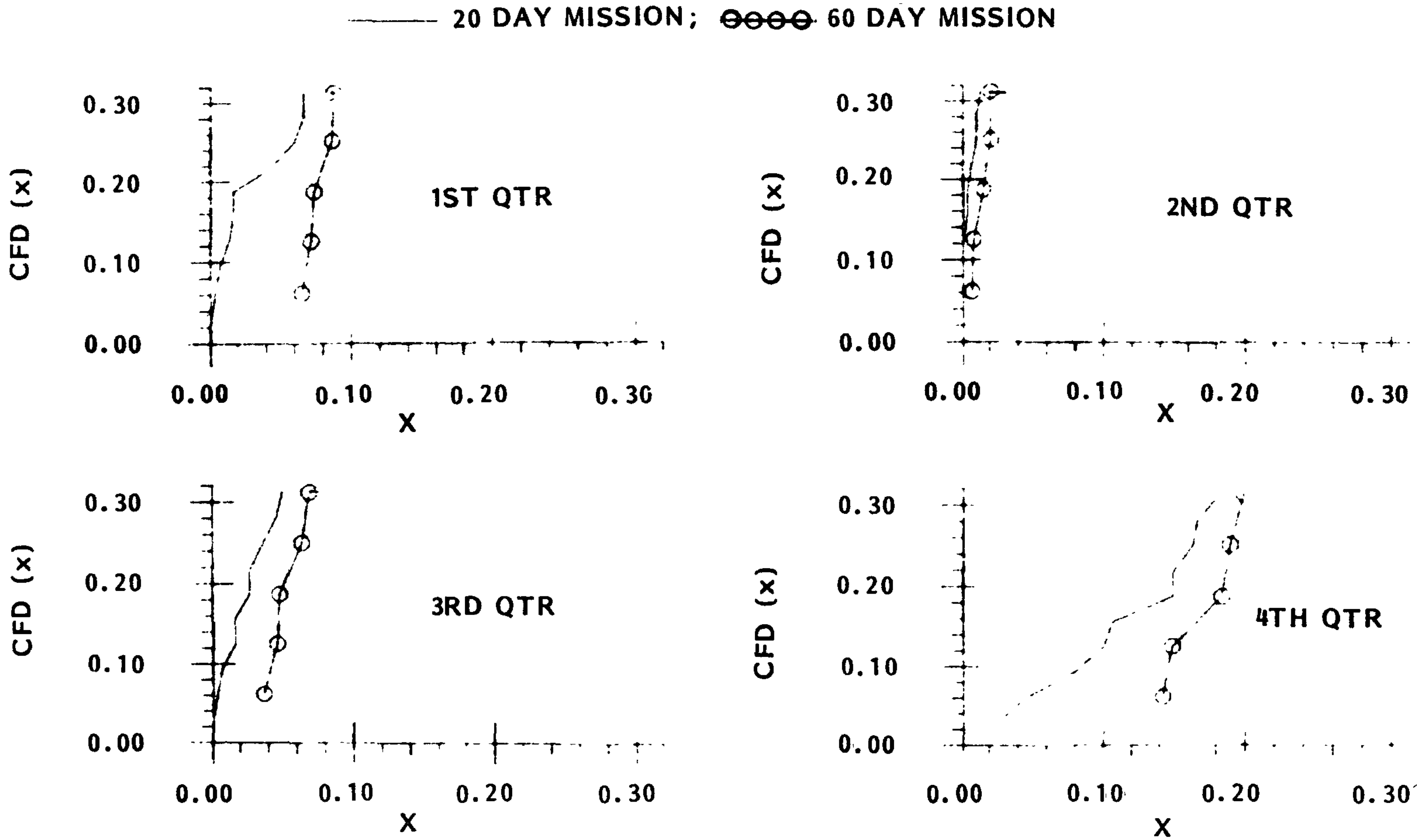
LOW RANGE OF PROBLOOK–POINT #1
(50.5N,40.5E)



*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

LOW RANGE OF PROBLOOK—POINT #2
(25N,110E)

PROBLOOK CFDs* – 60% THRESHOLD

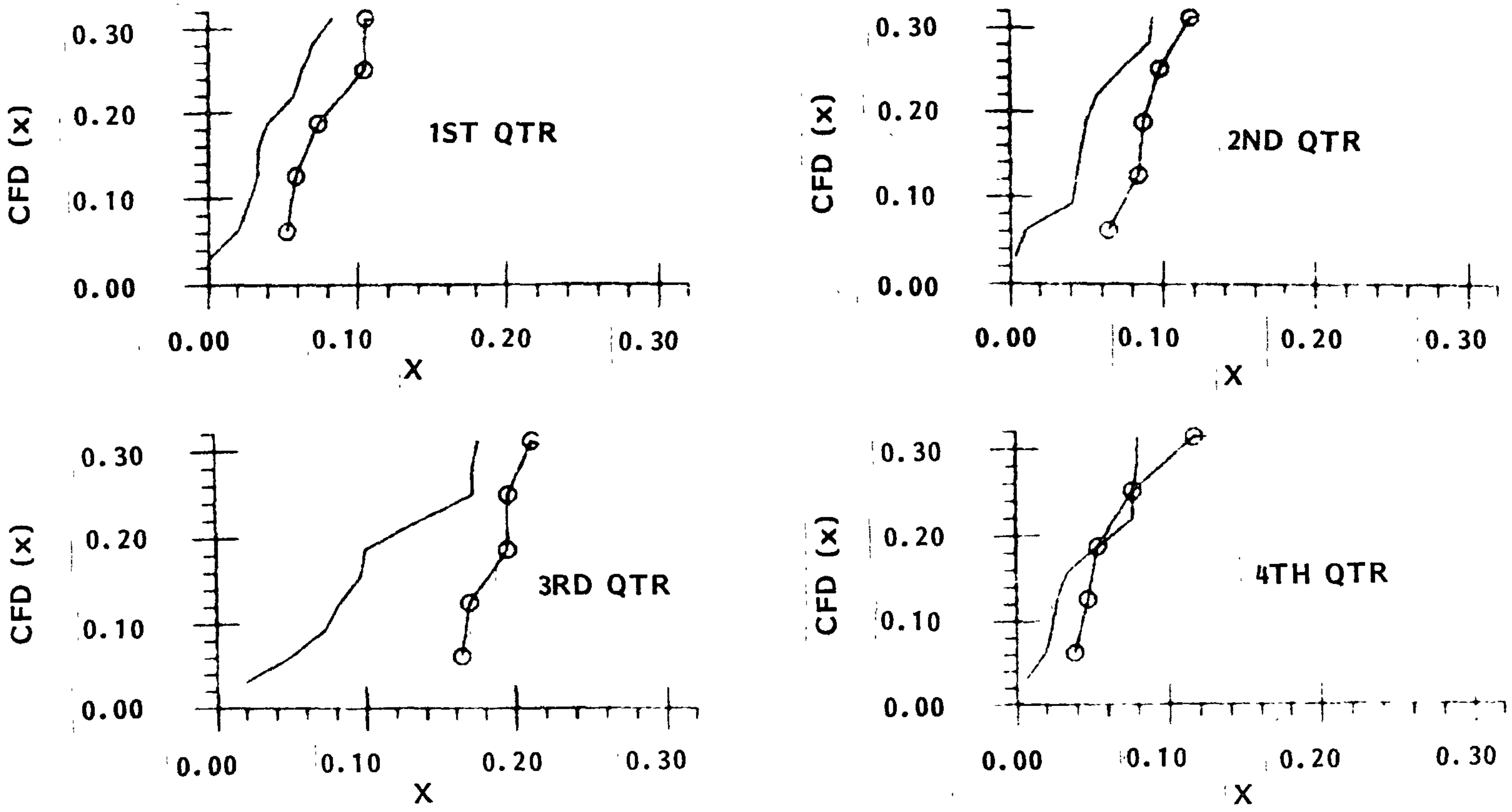


*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

LOW RANGE OF PROBLOOK—POINT #3
(50N,15E)

PROBLOOK CFDs* – 60% THRESHOLD

—— 20 DAY MISSION; -o-o-o-o- 60 DAY MISSION



*CFD (x) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

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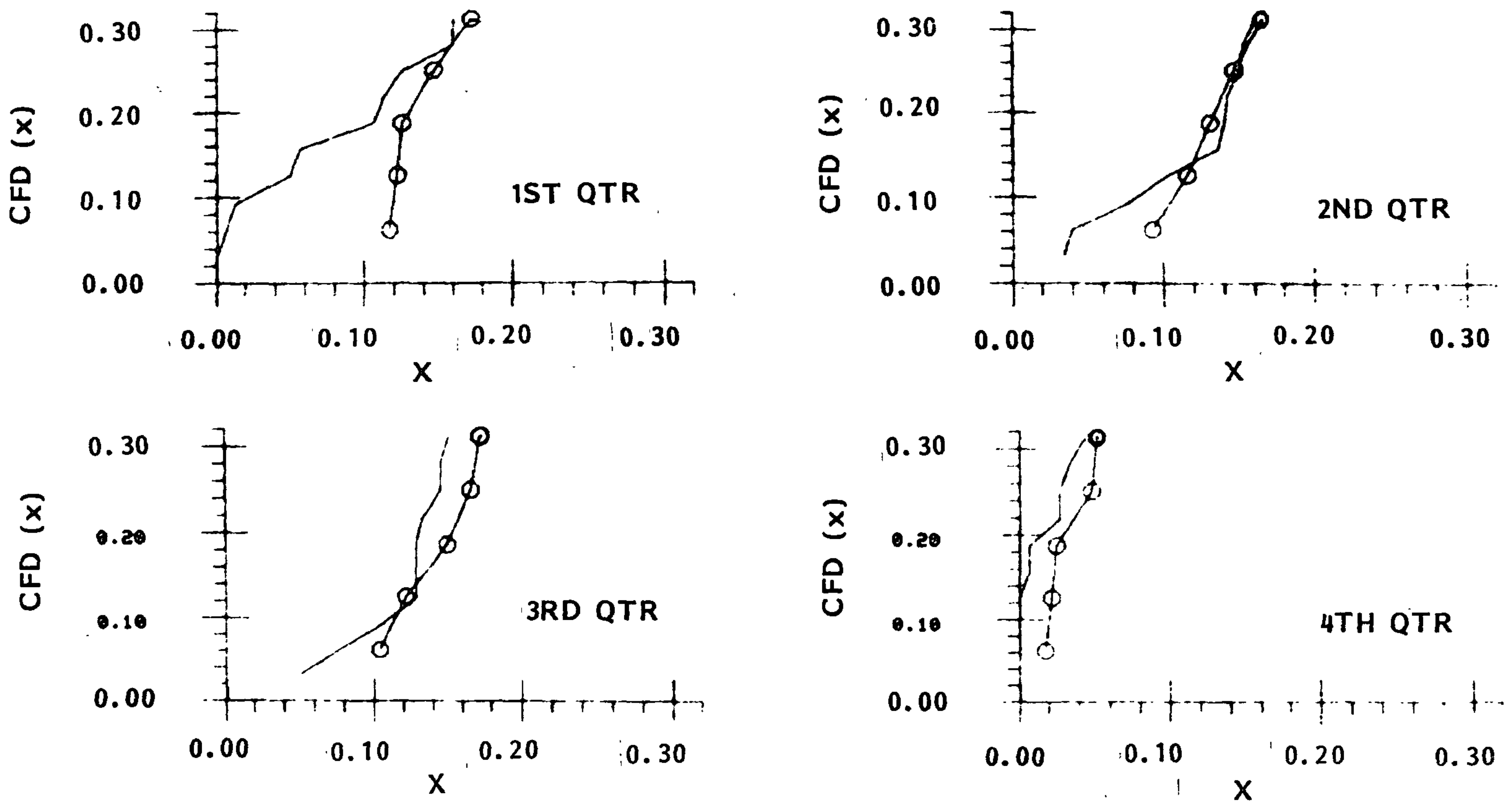
LOW RANGE OF PROBLOOK—POINT #4
(55.7N,37.6E)

PROBLOOK CFDs* – 60% THRESHOLD

——— 20 DAY MISSION; ⊖⊖⊖⊖ 60 DAY MISSION



*CFD (X) IS THE PROBABILITY THAT PROBLOOK IS BETWEEN O AND X

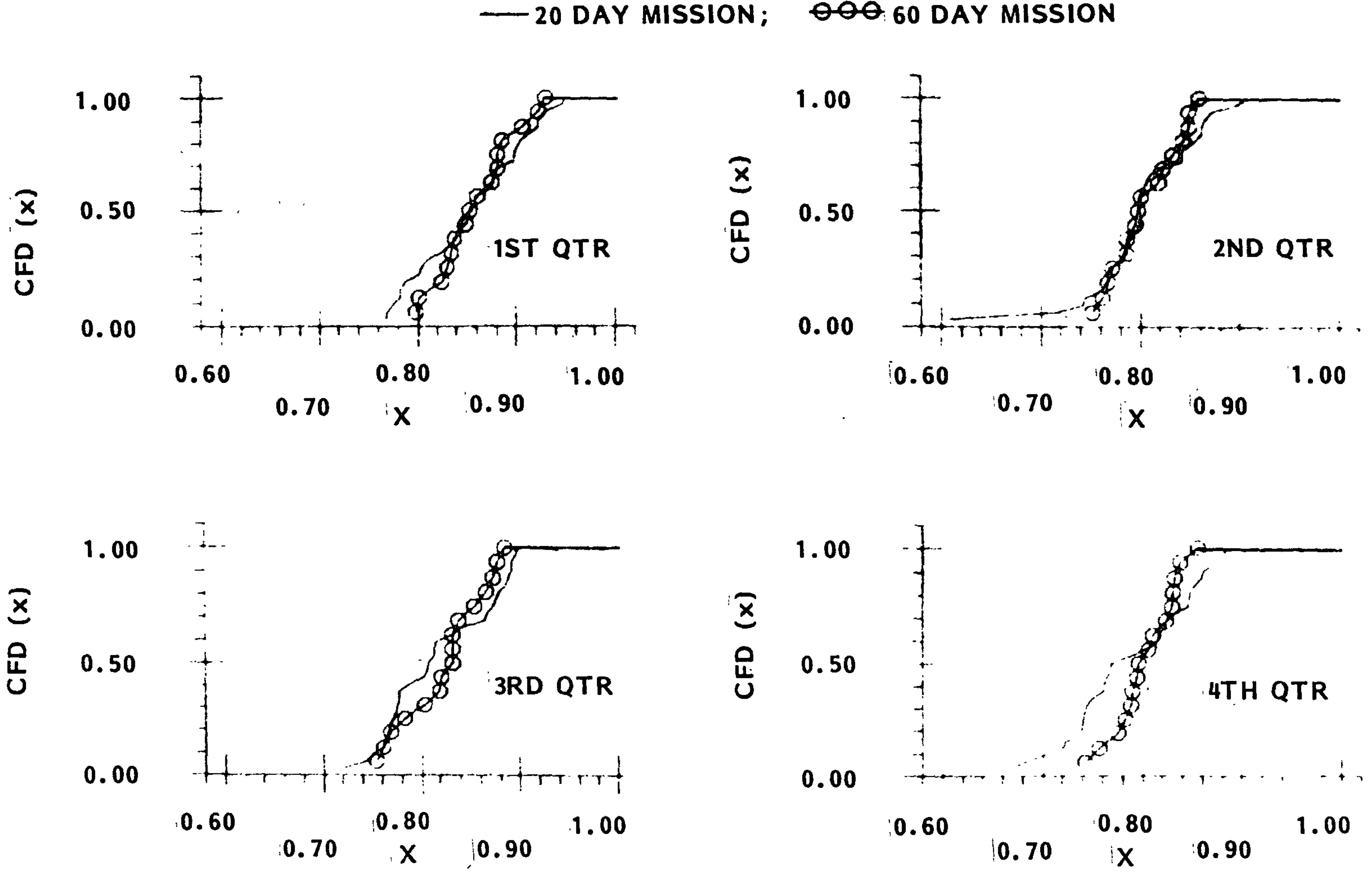
PROBCLEAR STATISTICS, 20 DAY AND 60 DAY MISSIONS

The next four charts provide CFD's for PROBCLEAR and the fifth displays mean and standard deviation values for these distributions. PROBCLEAR (as used here) is an estimate of the expected value of full sky clearness (1 - cloud cover), based on a weighted average of those cases when clearness exceeded a 60% threshold. These data help support the assumption of 80% cloud-free take when a 60% threshold is used. The relationship between full sky clearness and fraction of cloud free imagery is covered in a subsequent chart which indicates that only 70% clearness is generally required to obtain 80% cloud free imagery.

It should also be noted that the imagery from 60 day missions will often be more cloud free than that for 20 day missions but that this difference is much less than the point-to-point and quarter-to-quarter variations.

PROBCLEAR—POINT#1

PROBCLEAR CFDs*; 60% THRESHOLD

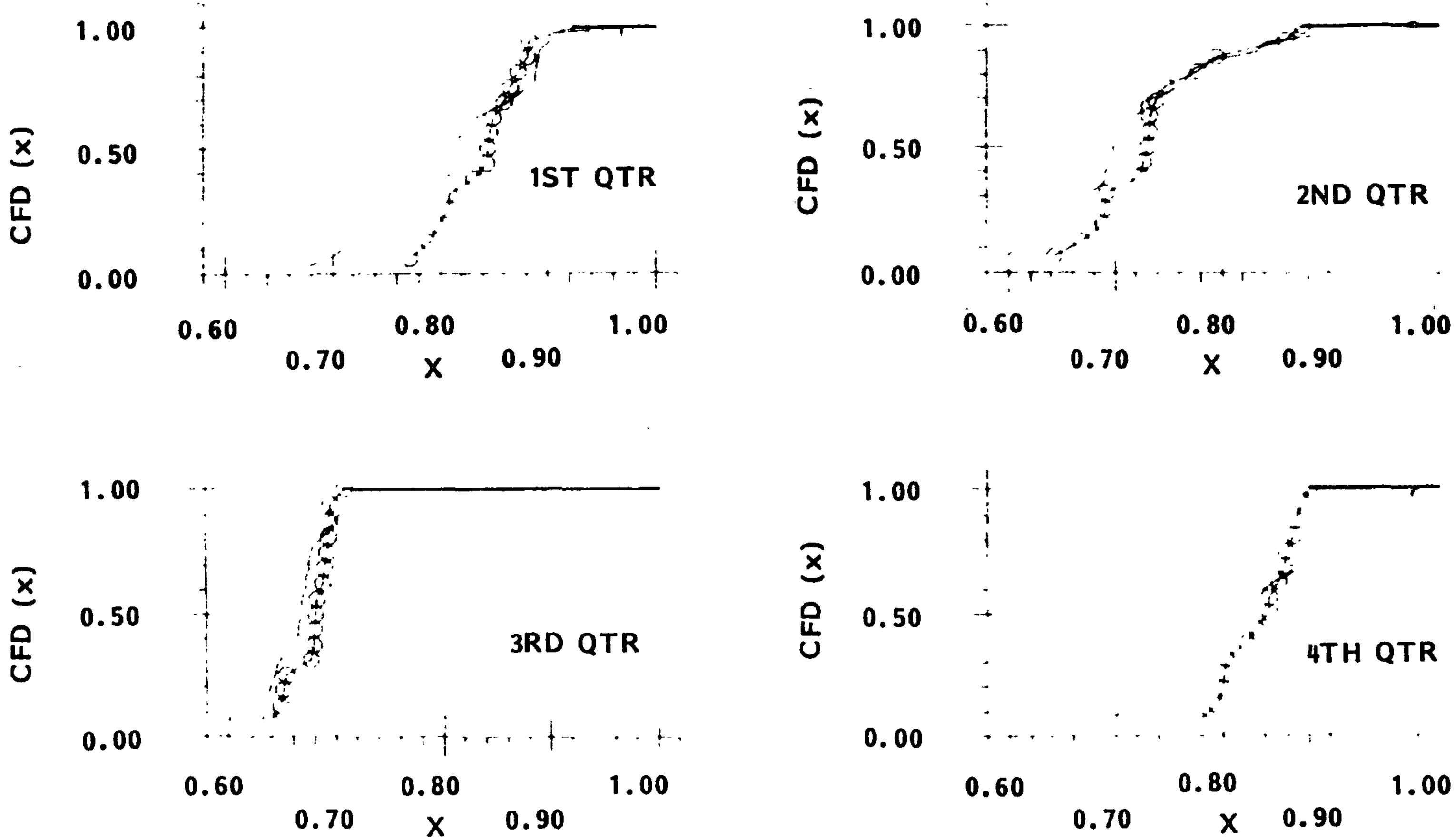


*CFD (x) IS THE PROBABILITY THAT PROBCLEAR IS BETWEEN O AND X

PROBCLEAR—POINT #2

PROBCLEAR CFDs*; 60% THRESHOLD

——20 DAY MISSION; -o-o-o- 60 DAY MISSION

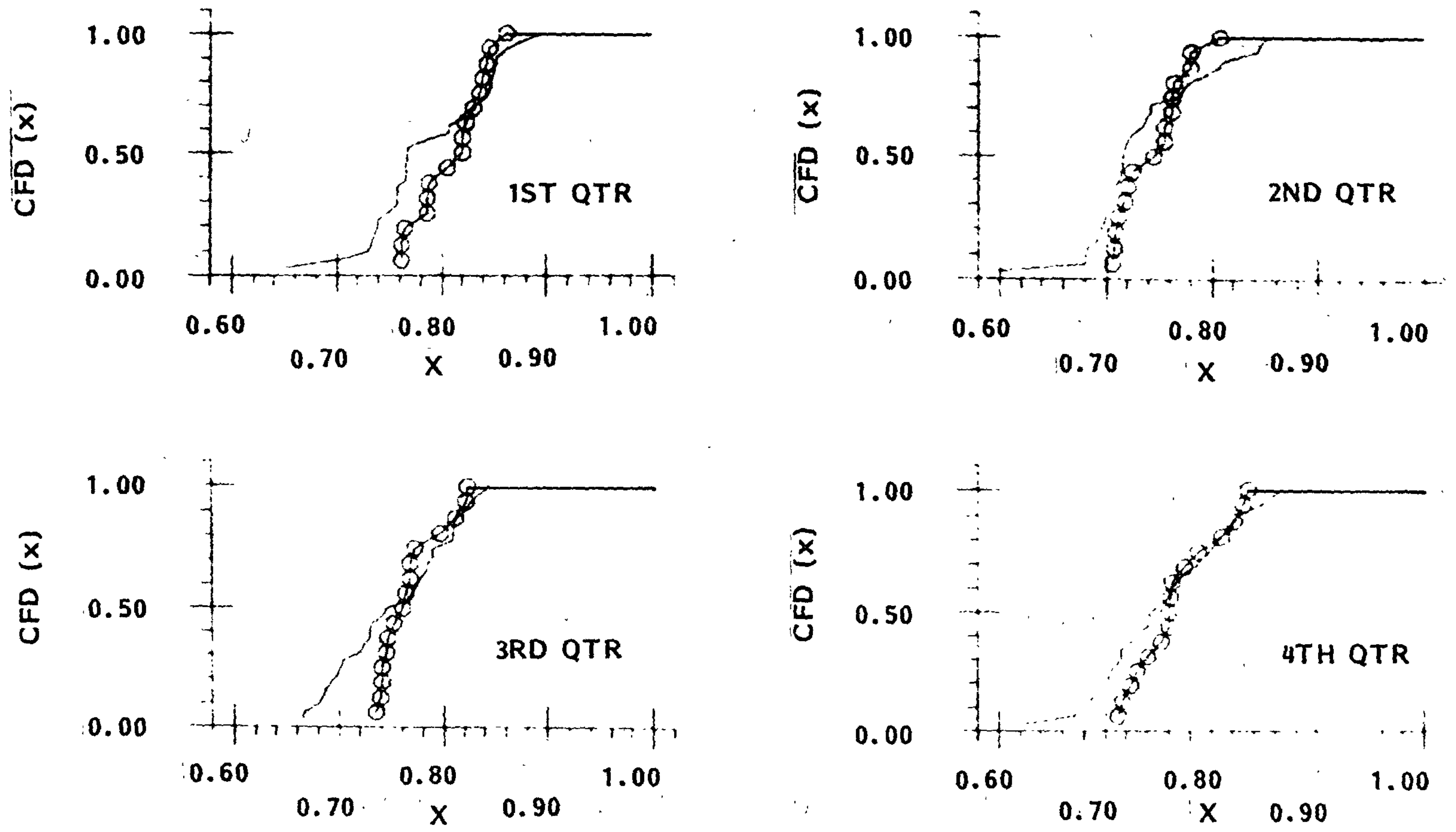


*CFD (x) IS THE PROBABILITY THAT PROBCLEAR IS BETWEEN O AND X

PROBCLEAR—POINT #3

PROBCLEAR CFDs*; 60% THRESHOLD

—20 DAY MISSION; -o-o-o- 60 DAY MISSION

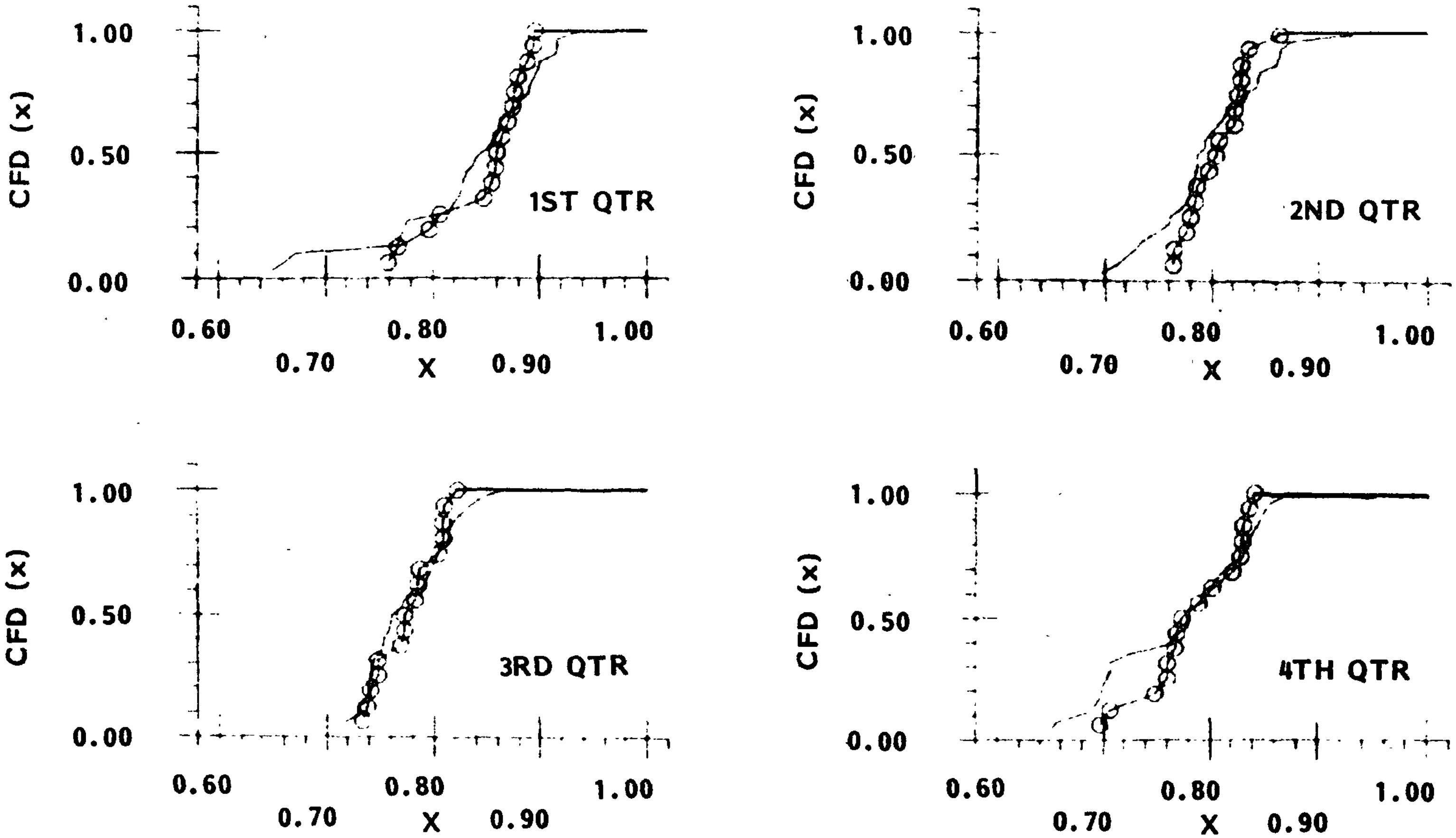


*CFD (x) IS THE PROBABILITY THAT PROBCLEAR IS BETWEEN O AND X

PROBCLEAR—POINT #4

PROBCLEAR CFDs*; 60% THRESHOLD

——20 DAY MISSION; -o-o-o- 60 DAY MISSION



*CFD (x) IS THE PROBABILITY THAT PROBCLEAR IS BETWEEN O AND X

PROBCLEAR MEAN AND STANDARD DEVIATION BY QUARTER 60% THRESHOLD

POINT	MISSION DURATION (DAYS)	1st Qtr		2nd QTR		3rd QTR		4th QTR	
		$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
#1 Western USSR	10	.846	.062	.795	.071	.808	.066	.786	.067
	20	.855	.054	.803	.057	.819	.054	.789	.061
	60	.860	.039	.806	.034	.825	.042	.804	.031
#2 Southern China	10	.809	.090	.722	.095	.660	.033	.800	.100
	20	.819	.071	.720	.081	.665	.032	.821	.077
	60	.842	.040	.739	.063	.679	.020	.837	.033
#3 Europe	10	.792	.063	.724	.066	.736	.065	.744	.073
	20	.790	.058	.735	.056	.754	.054	.753	.059
	60	.810	.032	.745	.031	.769	.030	.767	.040
#4 Moscow	10	.825	.081	.786	.068	.761	.064	.768	.076
	20	.835	.073	.797	.052	.776	.040	.771	.067
	60	.849	.043	.805	.028	.778	.029	.785	.045

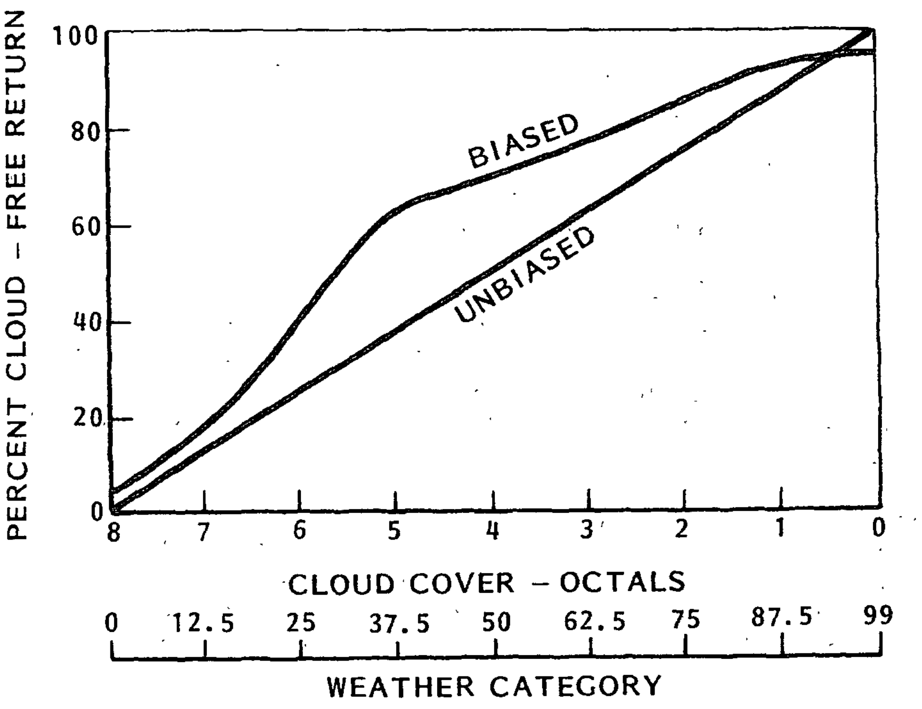
TYPICAL BIAS FOR ESTIMATION OF CLOUD-FREE TAKE

It is well known that the fraction of cloud free imagery (looking down) is generally greater than the complement (1-N) of cloud cover (looking up). This "bias" is produced largely because downward viewing is within perhaps ±45° of nadir while cloud cover is defined as the average over the entire sky. The magnitude of this effect is a function of the type and vertical distribution of clouds; and various methods have been used to estimate its impact for operational systems, e.g., the "Kennedy correction" for area search systems. Such sophistication is not needed for the current study. It is sufficient here to show the general magnitude of the look-down vs look-up variation to further support the assumption that a single image taken with a clearness threshold of 60% can be expected to meet the 80% take requirement for the area covered.

This chart shows the result of estimating the subject bias based on 3 flights of a narrow field-of-view satellite system. It indicates that on the average, 80% of the surface can be viewed when the weather category (full sky clearness) is about 70%. This 70% value is almost always exceeded when the threshold is 60% as shown on the previous four charts showing PROBCLEAR distributions.

TYPICAL BIAS FOR ESTIMATION OF CLOUD-FREE TAKE

(BASED ON RESULTS FOR NARROW FOV SYSTEM)



TYPICAL WEATHER PREDICTION STATISTICS

A factor not incorporated in the Volume I quantity performance analysis was the effect of weather prediction accuracy. This chart provides the following input data relating to this problem as provided by the Air Weather Service:

1. A typical "Pre-Ver" matrix derived from the results of Hexagon mission #14.

2. A typical weather distribution for a dense target area, to be used with the matrix to estimate the magnitude of the impact of weather prediction errors on performance analysis.

The matrix is the "pre for all ver" type; that is it provides the cumulative frequency distribution of prediction category (pre) for each category of verified weather (ver). The weather categories in each case are "one minus N" weather or the complement of cloud cover. Predicted weather is that used for targeting while verified is that used post-pass to determine whether each area imaged can be considered covered (so that it can be dropped from consideration of repeated targeting).

To determine the percentage of time in various areas of "pre-ver" space (see next chart), it is necessary to consider the percentage of time that each of the ver categories occurs. A typical distribution of weather for one of the points used in the Volume I analysis is shown at the right. The month of April in Moscow was chosen for the example since its PROBLOOK value (60% threshold) is 0.22 (22%), near the middle of the range of typical dense area weather (about 0.15 to 0.25).

TYPICAL WEATHER PREDICTION STATISTICS*

TYPICAL PRE-VER MATRIX(1)

PRE CATEGORY

VER CATEGORY	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
0	25	46	61	72	81	86	90	92	94	95	96	96	97	97	97	98	98	99	99	99	99
5	13	31	48	61	73	80	85	89	91	93	94	95	95	96	97	97	98	98	99	99	99
10	11	26	43	57	69	77	84	88	90	92	93	94	95	95	96	97	98	98	99	99	99
15	9	22	37	51	64	73	80	85	88	90	91	92	93	94	95	96	97	98	98	99	99
20	8	19	33	46	61	70	77	82	86	88	90	91	92	93	94	95	97	97	98	99	99
25	7	16	30	42	56	65	74	79	83	86	88	89	91	92	93	94	96	97	98	98	99
30	6	14	27	39	52	61	70	76	80	84	85	87	88	90	91	93	95	96	97	98	99
35	5	14	25	36	49	58	67	73	78	81	83	85	87	88	90	92	94	96	97	98	99
40	5	13	24	35	47	55	64	70	75	79	81	83	85	87	88	90	93	95	96	98	99
45	5	12	23	33	45	53	62	68	72	76	79	81	83	85	87	89	92	94	96	97	99
50	5	11	21	31	43	51	60	65	70	74	76	78	81	83	85	87	91	93	95	97	99
55	4	10	20	30	41	50	58	63	68	71	74	76	79	81	83	86	90	92	95	97	99
60	4	10	19	29	40	48	56	61	65	69	71	73	76	79	81	84	88	91	94	96	99
65	4	9	19	27	38	46	54	59	63	66	69	71	73	76	79	82	87	90	93	96	99
70	4	9	18	26	37	44	52	57	61	64	66	68	71	73	77	80	85	89	92	95	99
75	4	8	17	25	35	42	49	54	58	61	62	64	67	69	72	76	83	87	90	94	99
80	3	8	16	23	32	39	46	50	54	57	58	60	63	65	68	72	79	84	88	92	99
85	3	7	14	21	30	37	43	47	51	53	55	56	59	61	64	67	75	80	85	90	99
90	3	6	13	20	29	34	40	44	47	49	51	52	54	56	59	62	70	75	82	88	99
95	3	6	13	19	27	33	39	42	45	47	48	49	51	53	55	58	66	71	76	85	99
100	1	4	9	13	18	21	25	27	29	30	31	31	32	34	35	37	43	47	52	60	99

(1) BASED ON HEXAGON MISSION NO. 14

TYPICAL CLIMATOLOGY(2)

CATEGORY	FREQ %	
0	9.0	78.0%
5	13.6	
10	12.6	
15	10.5	
20	8.7	
25	6.6	
30	4.9	
35	2.6	
40	2.2	
45	2.5	
50	2.5	
55	2.3	
60	1.8	22.0%
65	1.7	
70	2.2	
75	2.2	
80	2.1	
85	2.1	
90	1.4	
95	2.7	
100	5.8	

(2) FOUR YEAR AVE FOR APR, POINT NO. 4 (MOSCOW)

*EACH NUMBER IN THIS MATRIX IS THE PROBABILITY, IN PERCENT, THAT THE INDICATED VERIFIED WEATHER (ROW HEADER) THE PREDICTED WEATHER LEVEL WAS EQUAL TO OR LESS THAN THAT INDICATED (COLUMN HEADER).

TYPICAL IMPACT OF TARGETING THRESHOLD ON ACCESS AND WASTAGE

The percentages on this chart show the distributions of the relationship between predicted (Pre) and verified (Ver) weather data for the typical case identified on the previous chart. In all cases shown, a 60% level is considered for ver, since the Volume I analysis considered imagery to be successful when taken above this threshold. It can be seen that if the targeting (Pre) threshold were set at 60%, fully successful imagery would have resulted only 10.3% of the time rather than the 22% possible. Thus, the curves of P(≥1) in Volume I should be entered with a value of less than half the total access opportunities. The 7.1% value at the upper right of this pattern is indicative of film wastage (i.e., cloudy imagery).

Lowering the targeting threshold from 60% to 40% produces the pattern on the left. The main message here is that by lowering the threshold by 1/3 the percentage of successful opportunities (D) increases by about 10% but film wastage (B) increases by nearly 100%. Thus to increase the number of access opportunities by 10% one must be prepared to waste twice as much film.

Moving the targeting threshold to relatively lower values would, nevertheless be appropriate for pallet missions due to their short mission life and relatively low penalty for extra film supply.

The overall impact of prediction errors on the Volume I analysis is that the performance probabilities (probability of at least one look) are quite optimistic in absolute value. However, the main thrust of the study was to compare various systems which are all subject to the same weather prediction inaccuracies. Thus the comparative evaluation can be considered valid and the study conclusions would not be changed by a more sophisticated analysis which included the effects of weather prediction errors.

IMPACT OF TARGETING THRESHOLD ON ACCESS AND WASTAGE

20% THRESHOLD
PRE

VER	20	100
0	A 40	B 38
60	C 4.5	D 17.5
100		

40% THRESHOLD
PRE

VER	40	100
0	A 64.7	B 13.3
60	C 10.6	D 11.4
100		

60% THRESHOLD
PRE

VER		100
0	A 70.9	B 7.1
60	C 11.7	D 10.3
100		

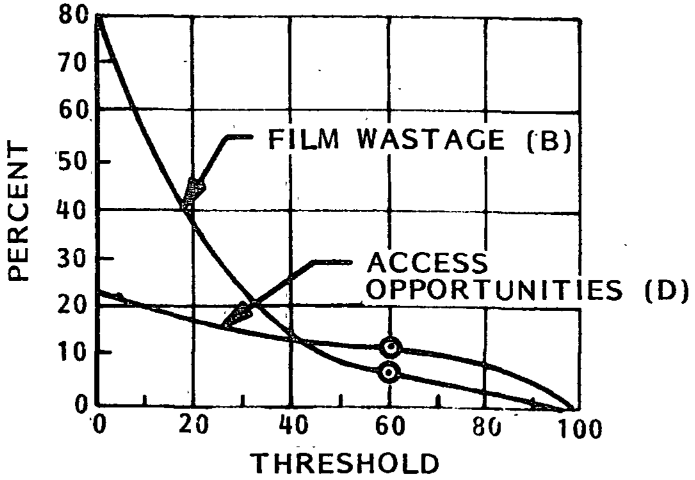
80% THRESHOLD
PRE

VER	80	100	
0	A 74.1	B 3.9	78%
60	C 13.8	D 8.2	22%
100			

A – SYSTEM OFF, WEATHER POOR
B – SYSTEM ON, WEATHER POOR (WASTED FILM)
C – SYSTEM OFF, WEATHER GOOD (MISSED OPPORTUNITIES)
D – SYSTEM ON, WEATHER GOOD (SUCCESSFUL OPPORTUNITIES)

NOTE: IN ALL CASES

A+B = 78%
C+D = 22%



APPENDIX D

PERFORMANCE ANALYSIS FACTORS

IMAGE QUALITY PERFORMANCE CONSIDERATIONS

Contrast and Smear are the dominant factors which determine the performance of a given optical system. Image quality deteriorates with low sun angles not only because of higher smear due to longer integration (exposure) times but also because of reduction of contrast. Contrast is a function of weather conditions, illumination geometry and viewing geometry. Long slant paths for both illumination and viewing increase haze and reduce transmission. Consequently, obliquities (scanning angles) greater than 40 to 45° are not productive.

There has been a community practice to evaluate prospective optical systems for representative conditions such as 600 foot-lamberts (30° sun angle) and 2:1 contrast. This practice is often adequate for the purpose of sizing aperture and focal length of a candidate system. However, a realistic evaluation of system performance requires a sophisticated haze and transmission model as well as a smear model. Recent operational experience has shown that a sample of standard CORN targets having 7 and 33 percent reflectance (4.75:1) have an apparent (entrance pupil) contrast of 2:1 for sun angles of 50 to 55°, while contrasts in the range of 1.2:1 to 1.4:1 occur for sun angles from 5 to 20°. Since pallet operations from ETR will experience a regime of low sun angles especially on missions of 3 weeks or longer duration, contrast, attenuation, and smear are important considerations for the SCS concept.

Estimates of the range of NIIRS ratings indicated in Volume I are approximate. The NIIRS rating corresponding to a given GRD depends on subjective factors including such things as familiarity with the target. Thus, an old well known target for which periodic surveillance is maintained will have a higher score than a new target from an unfamiliar cultural environment. There have been many attempts to correlate NIIRS and GRD according to a model: $\text{NIIRS} = A + B\,\ell n(\text{GRD})$. The range of the coefficients, A and B suggest the risk of that approach. Recently a more elegant probability model has been proposed. This model requires a triplet of coefficients which reflect variations of target type and optical system, etc. It is not clear that this more sophisticated approach can be extrapolated for application to new systems. Consequently, NIIRS predictions remain an undertaking involving considerable uncertainty.

PERFORMANCE ANALYSIS FACTORS

INTRODUCTION

This appendix provides:

1. A brief discussion of considerations applicable to the evaluation of SCS image quality performance.

2. A description of the method used in the SCS study for computation of the probability of at least one look, P (≥ 1), the principal measure of quantity performance used in the study.

3. A set of P (≥ 1) results not presented in Volume I because it did not contribute directly to major study conclusions.

COMPUTATION OF "PROBABILITY OF AT LEAST ONE LOOK"

The probability of at least one look, P (≥ 1), is defined in this study as: the probability of having at least one opportunity to image all portions of a 250 nm east-west strip in a dense target area at times when the weather in each portion (taken as a 50 nm by 50 nm square) was $\geq$ 60% cloud free. The justification for using this measure of quantity performance is provided in Volume I. The chart here provides greater detail on the method used to compute P (≥ 1).

The input weather data for a given region, as indicated on the chart, consists of 32 probability values, which make up the weather pattern probability vector, WPPV. When the imaging swath is $\geq$ 250 nm, the WPPV is the top row of the pass transition matrix, PTM, since it defines success probabilities after the first pass (access opportunity). When the imaging swath is < 250 nm, the WPPV must be screened by multiplication with a imaging limit screening matrix to become the top row of the PTM.

To understand the summing process used to obtain the other elements of the PTM, it is necessary to consider its use by, first, defining the success probability vector, SPV (see lower left box). This vector is to be multiplied by the PTM for each pass to obtain a new SPV after the pass. Each element of the PTM, P_{ij}, must convert the probability for success in the i th pattern before the pass to probability of success in the j th pattern after the pass. It is, then, as stated on the chart, the conditional probability associated with this transition. Its value is computed by adding the probabilities for the various weather patterns (mutually exclusive events) which will allow this transtion to occur; that is, each term of the PTM is a sum of the appropriate probabilities in the top row of the matrix.

To obtain the total probability of success in the j th pattern after the pass, probabilities for the various ways of obtaining that result must be summed:

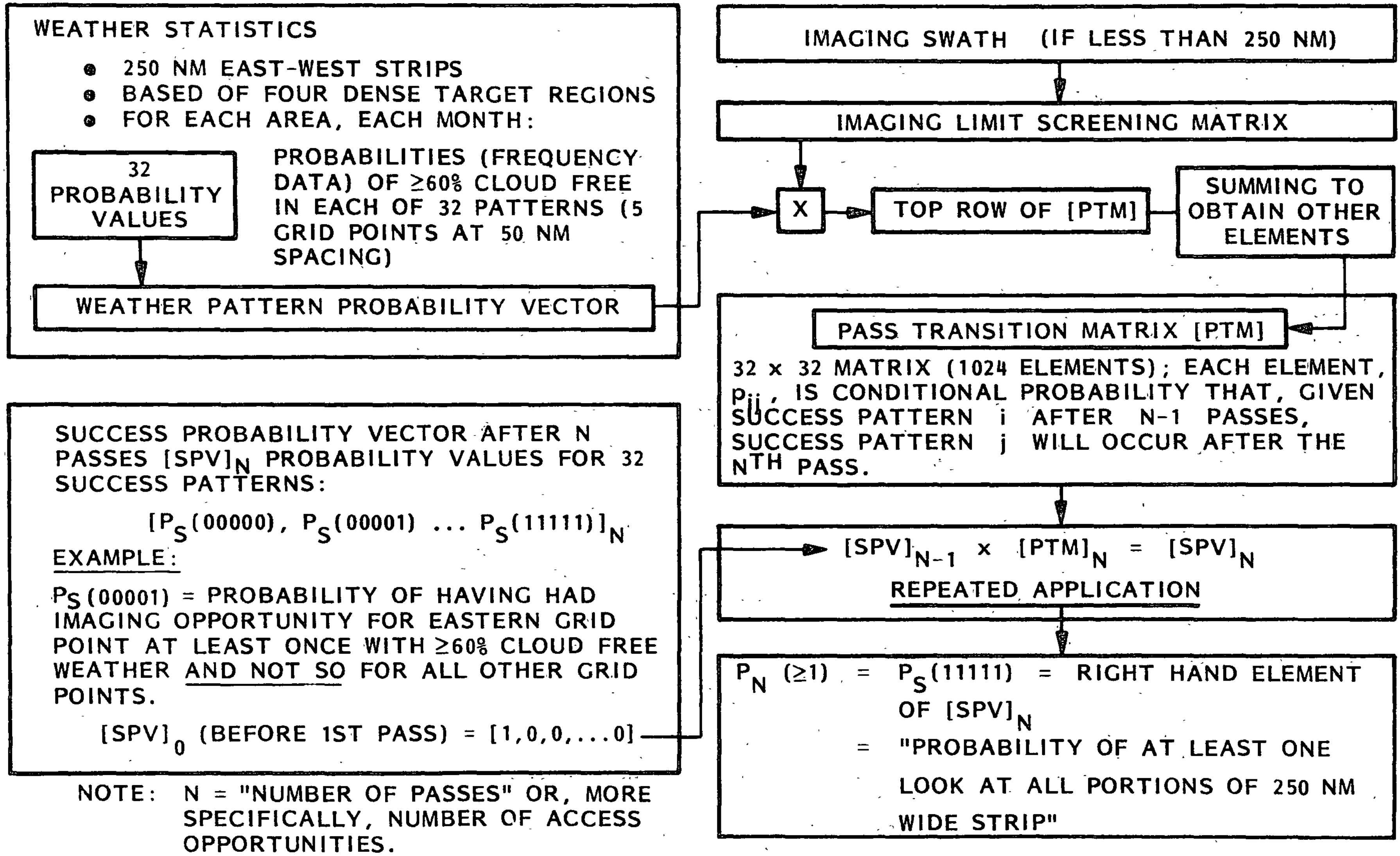
$$\left[P_s\ (j)\right]_N = \sum_i p_{ij} \left[P_s\ (i)\right]_{N-1}$$

This equation is, of course, implicit in the definition of the matrix multiplication identified in the next to the bottom box on the right.

COMPUTATION OF "PROBABILITY OF AT LEAST ONE LOOK" (CONT.)

After N passes, P (≥ 1) is the right hand element of the SPV, the probability that all five areas areas can have been imaged at least once. It has been found helpful in understanding this process to carry out numerical examples with 2 or 3 elements (boxes in the strip) rather than 5, that is, involving 4 x 4 or 8 x 8 elements in the PTM.

COMPUTATION OF "PROBABILITY OF AT LEAST ONE LOOK"



WEATHER STATISTICS

- 250 NM EAST-WEST STRIPS
- BASED OF FOUR DENSE TARGET REGIONS
- FOR EACH AREA, EACH MONTH:

32 PROBABILITY VALUES

PROBABILITIES (FREQUENCY DATA) OF ≥60% CLOUD FREE IN EACH OF 32 PATTERNS (5 GRID POINTS AT 50 NM SPACING)

WEATHER PATTERN PROBABILITY VECTOR

IMAGING SWATH (IF LESS THAN 250 NM)

IMAGING LIMIT SCREENING MATRIX

X

TOP ROW OF [PTM]

SUMMING TO OBTAIN OTHER ELEMENTS

PASS TRANSITION MATRIX [PTM]

32 x 32 MATRIX (1024 ELEMENTS); EACH ELEMENT, p_{ij}, IS CONDITIONAL PROBABILITY THAT, GIVEN SUCCESS PATTERN i AFTER N-1 PASSES, SUCCESS PATTERN j WILL OCCUR AFTER THE N^{TH} PASS.

SUCCESS PROBABILITY VECTOR AFTER N PASSES $[SPV]_N$ PROBABILITY VALUES FOR 32 SUCCESS PATTERNS:

$$[P_S(00000),\ P_S(00001)\ \ldots\ P_S(11111)]_N$$

<u>EXAMPLE:</u>

$P_S(00001)$ = PROBABILITY OF HAVING HAD IMAGING OPPORTUNITY FOR EASTERN GRID POINT AT LEAST ONCE WITH ≥60% CLOUD FREE WEATHER AND NOT SO FOR ALL OTHER GRID POINTS.

$[SPV]_0$ (BEFORE 1ST PASS) = [1,0,0,...0]

$[SPV]_{N-1} \times [PTM]_N = [SPV]_N$

REPEATED APPLICATION

$P_N(\geq 1) = P_S(11111)$ = RIGHT HAND ELEMENT OF $[SPV]_N$

= "PROBABILITY OF AT LEAST ONE LOOK AT ALL PORTIONS OF 250 NM WIDE STRIP"

NOTE: N = "NUMBER OF PASSES" OR, MORE SPECIFICALLY, NUMBER OF ACCESS OPPORTUNITIES.

PROBABILITY OF AT LEAST ONE LOOK IN GOOD WEATHER MONTHS

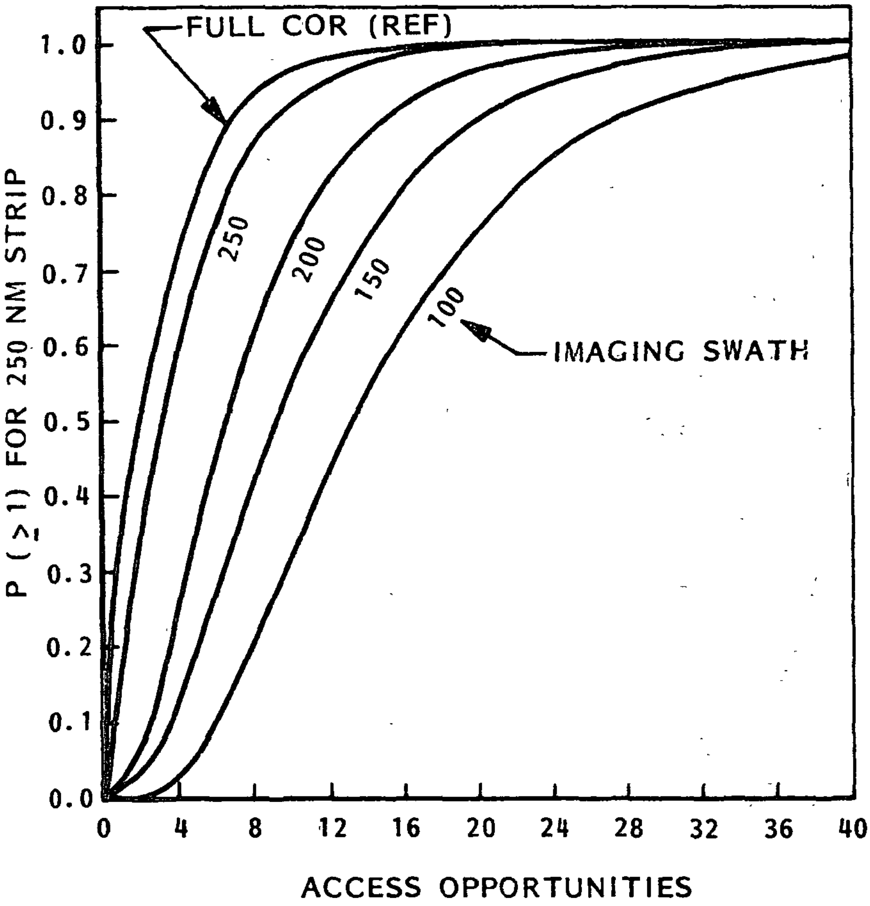
This chart presents a set of results which was not provided in Volume I since it did not contribute directly to study conclusions. It, however, helps confirm the conclusion that using a system with limited imaging swath has a severe effect on quantity performance.

It shows this to be true unless, with 15 to 20 accesses, the weather is considerably better than average in the dense target areas studied. Some data from these curves was also used in computation of P ($\geq$ 1) for representative weather by season, presented in Volume I.

PROBABILITY OF AT LEAST ONE LOOK IN GOOD WEATHER MONTHS

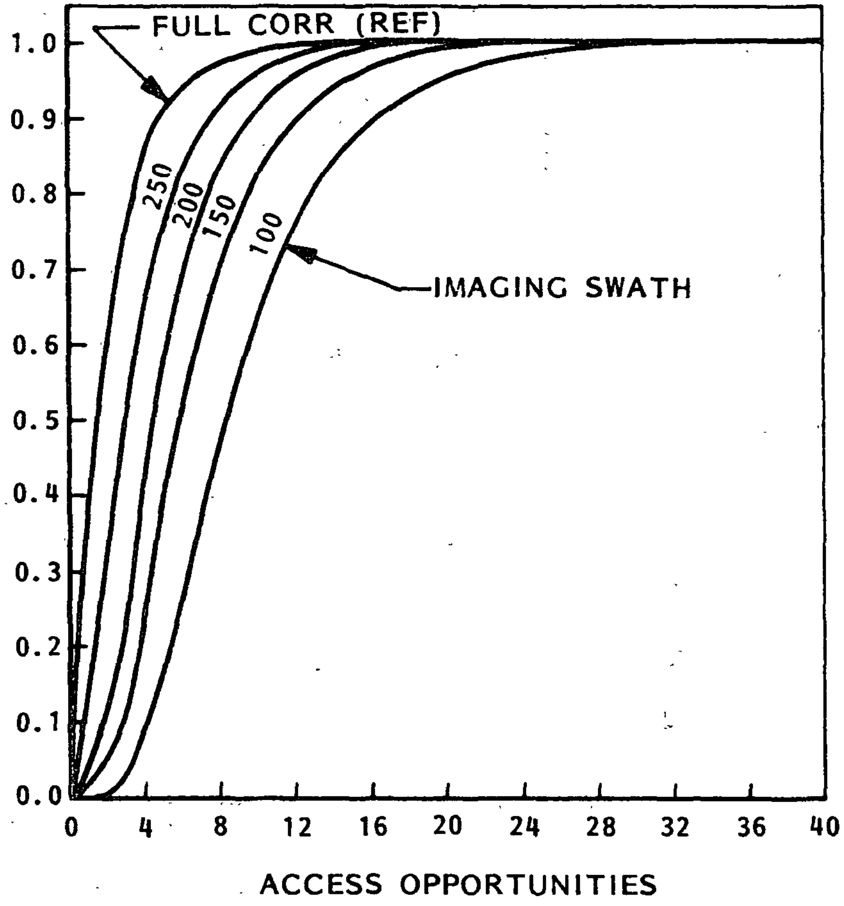
NOVEMBER, SOUTHERN CHINA
(25°N, 110°E)

P_L = 0.287 (+1.3σ), STRONG COR



MAY, WESTERN USSR
(50.5°N, 40.5°E)

P_L = 0.379 (+0.7 σ), MED WEAK COR



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