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TASK FINAL REPORT

on

COASTAL DATA ACCUMULATION POTENTIALS
FOR OPERATIONAL SYSTEMS USING AIRPLANES
(Report No. BCL-OA-TFR-76-1)

by

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to

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1.0 SUMMARY OF RESULTS

Potential users of SEASAT for remote sensing of coastal zone phenomena have established a need for resolutions beyond those attainable with SEASAT-A. One method of obtaining higher resolutions would be to fly the instruments aboard airplanes rather than a satellite. The task addressed in this study is to estimate the number of aircraft that would be required and to estimate the rate at which data would be accumulated. Only the East Coast from Maine to Key West is considered in this study. Three different coverage widths are used. The narrowest area is wide enough to cover all bay and estuary regions along the coast; a wider area includes all ocean out to twelve nautical miles from the coast; the maximum size area considered extends out to 200 nautical miles from the coast.

For purposes of estimating the data accumulation rates it is assumed that the entire coast is to be covered twice each day. The five instrument SEASAT payload is used with appropriate assumptions about wavelengths, polarizations and other parameters. To show the effect of resolution on data rates, two resolutions (25 m and 10 m) are used for the imaging radar and three resolutions (5 km, 1 km, 0.5 km) are used for the other instruments.

For purposes of determining coverage swath widths along the flight path it is assumed that all instruments have the same half-angle field of view; two values are used (45^{o} and 55^{o}). Aircraft altitudes from 10,000 ft to 65,000 ft are considered.

Before the analysis was begun, it was expected that the results would show significant trends in the numbers of aircraft required as a function of their capabilities; i.e. ceiling, cruising speed, endurance and so forth. These trends certainly exist in an abstract sense, and they will be shown later in the report. But when real, existing airplanes are considered, it turns out that there are enough different permutations such as high altitude but low speed vs. lower altitude but higher speed so that the only meaningful comparisons are between actual airplanes rather than abstract sets of parameters. Therefore, five specific airplanes currently being used by NASA for remote sensing have been chosen and the number of each type required for each mission has been estimated. (Later in the report a graph is presented which allows the reader to use any set of aircraft capabilities he chooses.) The aircraft types considered are the Lockheed U-2, Convair 990, Lockheed NP-3A, Lockheed NC-130B and the Martin WB-57F.

Figure 1 shows the number of each type aircraft required for each of the missions considered. The numbers shown are for the case of 55^{o} instrument coverage. When the field of view (FOV) is reduced to 45^{o} the numbers increase as shown in Figure 2. The increase is small for the narrow coverage cases but quite significant for the 200 mile case. This is because a single pass is adequate to cover many parts of the coast out to 12 miles regardless of which FOV is used, but for coverage to 200 miles many parallel passes are required and so the difference in swath width becomes important. This also explains why the numbers of aircraft necessary to cover the area out to twelve miles is not much larger than the number necessary to cover bays and estuaries alone.

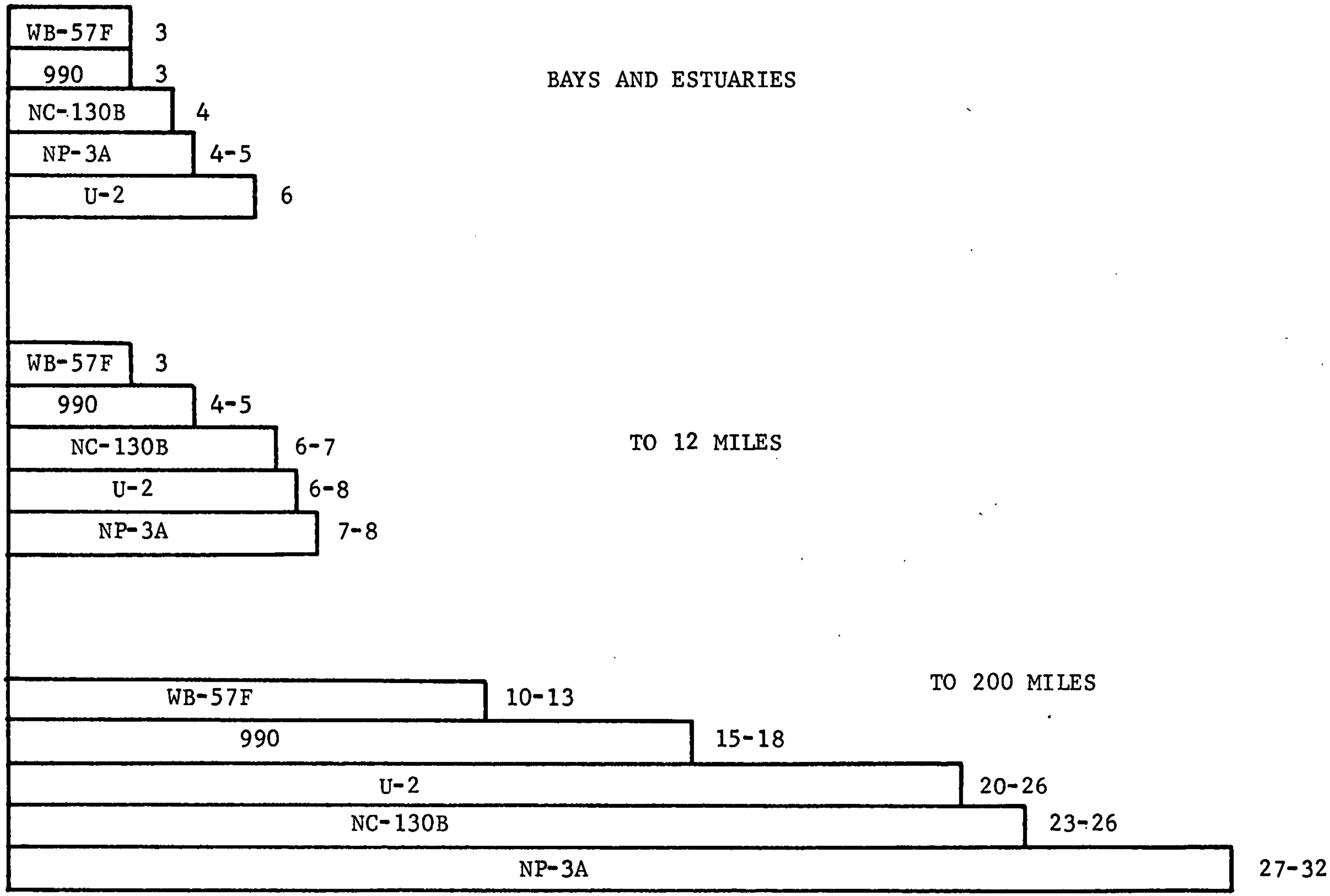


FIGURE 1. NUMBERS OF AIRCRAFT REQUIRED FOR TWICE DAILY COVERAGE OF EAST COAST WITH 55° HALF-ANGLE FIELD OF VIEW

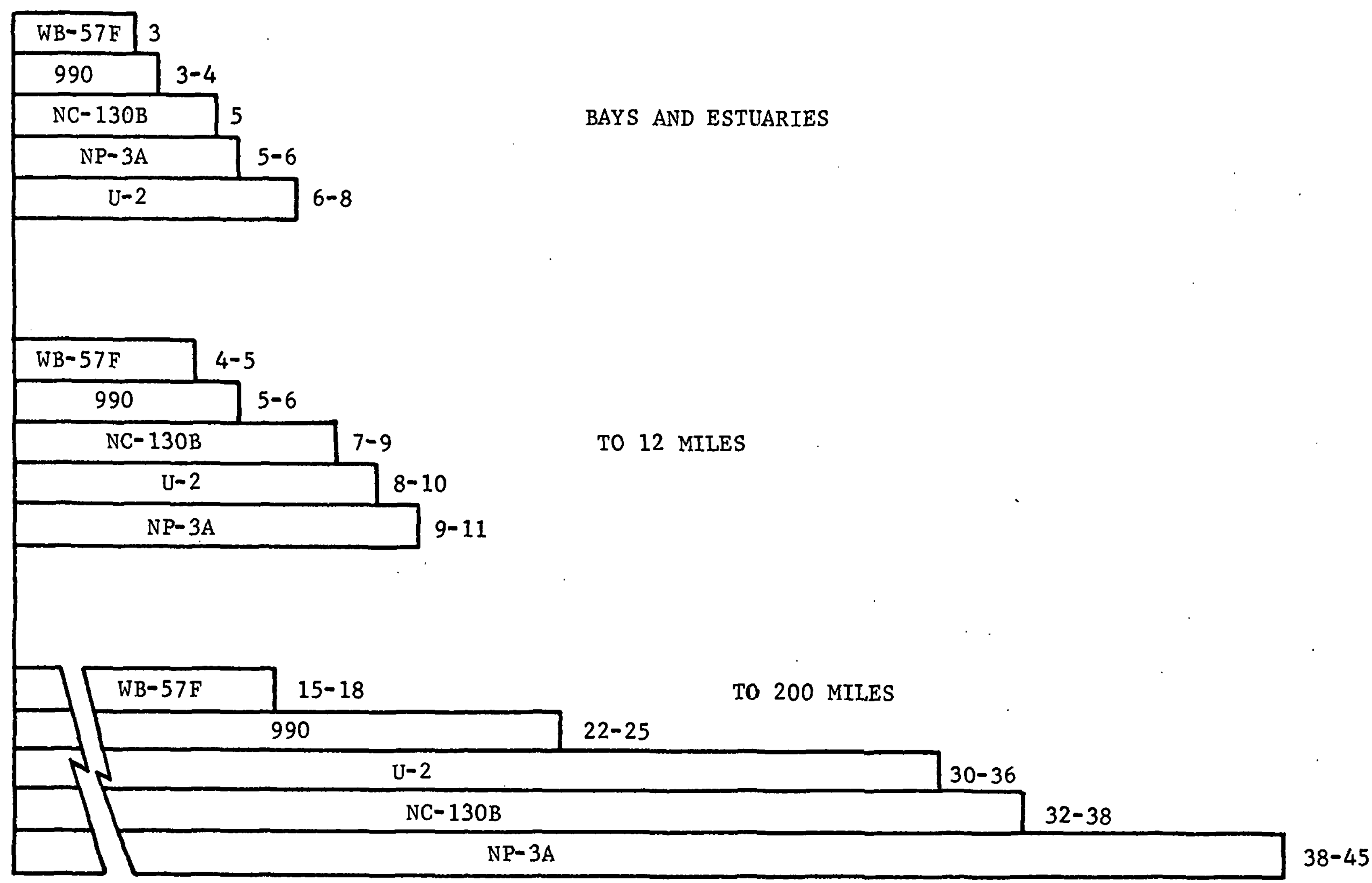


FIGURE 2. NUMBERS OF AIRCRAFT REQUIRED FOR TWICE DAILY COVERAGE OF EAST COAST WITH 45° HALF-ANGLE FIELD OF VIEW

The rate at which data is accumulated can be measured in many ways: bits per second, bits per flight mile, bits per square mile of ground coverage and so forth. For purposes of sizing the data processing load generated by these missions a more meaningful measure of the data rate is the number of bits per day generated by each instrument. This measure has the advantage of being independent of altitude, speed and other aircraft parameters. It depends only on the instruments used and the area covered. Table 1 summarizes the data rates for the various instruments and shows how they depend on resolution. The ranges of values for the imaging radar result from various assumptions about the number of bits per sample and the number of looks. It is worthy to note that these results would apply to a satellite as well as aircraft since they depend only on the instruments and the area being covered.

In order to give perspective to these numbers it is worthwhile to translate them into more concrete terms such as reels of computer tape per day. Since many different recording densities exist for computer tapes the results will be representative rather than specific but they are worth computing to develop a feel for the data rates that would be missing otherwise. Assuming 2400 foot, seven track reels recorded at 800 bits per inch, the imaging radar, for coverage of bays and estuaries alone, would fill from 28 to 1,400 reels of tape each day. For coverage out to 200 miles with 10 meter resolution the number could grow as high as 14,000 reels per day. Of course, the other instruments are not nearly so prolific. For all other instruments combined the figure for bays and estuaries would range from three hundreths of a reel to three reels per day. For coverage out to 200 miles between 0.3 and 30 reels of tape would be filled each day depending on the resolutions used.

It should be reiterated that computer tape recording densities vary widely and so the above figures should not be used as points of departure. The numbers given in Table 1 are the real measure of the amounts of data generated by these missions.

The remainder of this report gives the details of the anaylsis used to develop the results presented above.

Table 1. Data Accumulation Rates for Each Instrument (Bits/Day)

Instrument	Resolution	Amount of Data Accumulated Per Day(Bits) for: Bays and Estuaries	To 12 Miles	To 200 Miles
Imaging Radar				
	25 m	4 - 40 Billion	7 - 70 Billion	30 - 300 Billion
	10 m	20 - 200 Billion	40 - 400 Billion	200 - 2000 Billion
Scatterometer				
	5 km	0.2 Million	0.4 Million	2 Million
	1 km	6 Million	10 Million	40 Million
	0.5 km	20 Million	40 Million	200 Million
Microwave Radiometer				
	5 km	2 Million	4 Million	20 Million
	1 km	60 Million	100 Million	400 Million
	0.5 km	200 Million	400 Million	2000 Million
IR Radiometer				
	5 km	2 Million	4 Million	20 Million
	1 km	60 Million	100 Million	400 Million
	0.5 km	200 Million	400 Million	2000 Million
Altimeter				
		7 - 50 Thousand	10 - 80 Thousand	40 - 400 Thousand

2.0 DETAILS OF ANALYSIS

2.1 Assumptions about Instruments

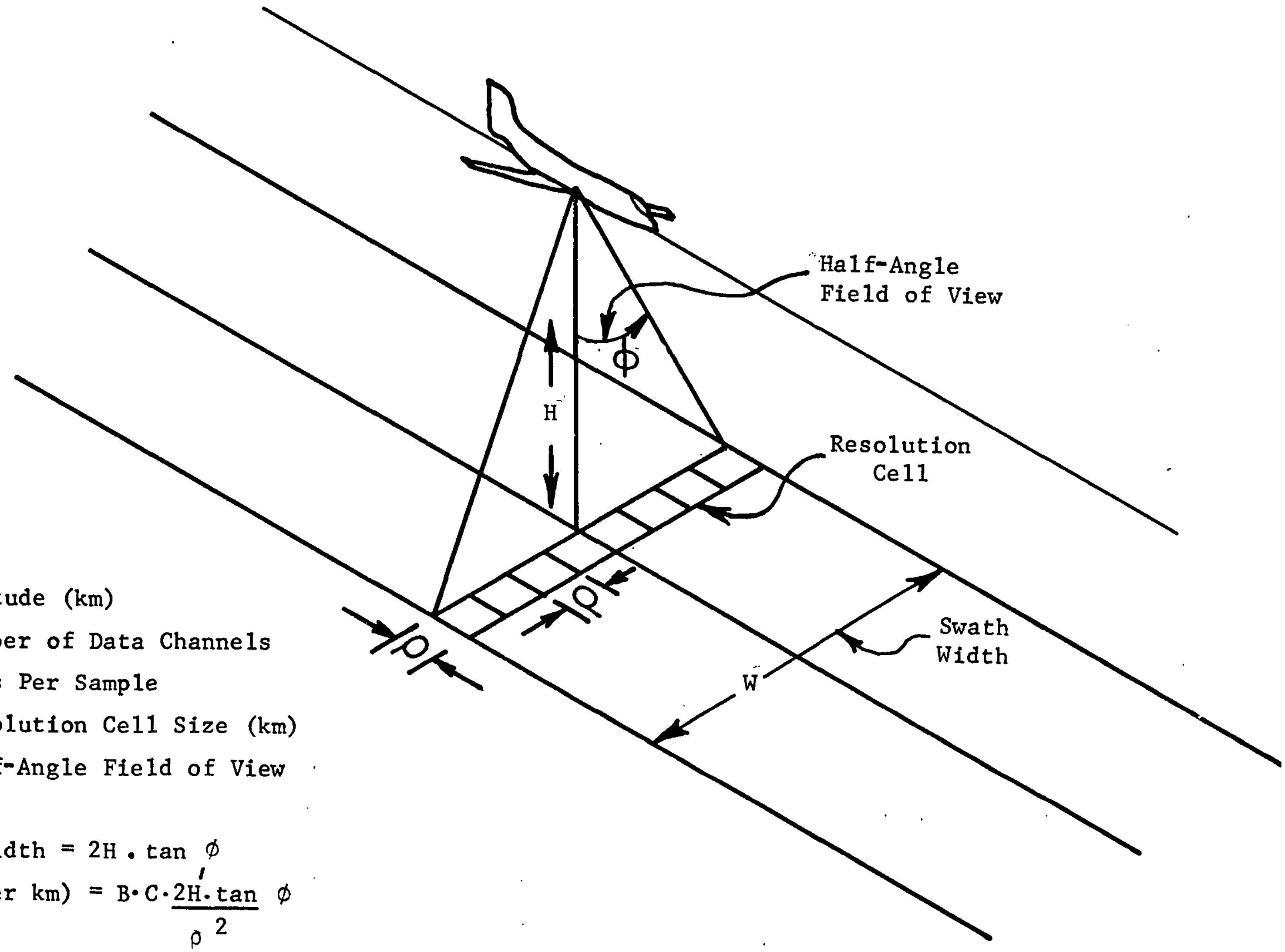
For purposes of estimating the rate at which data will be accumulated, the five instrument SEASAT payload is assumed with the wavelengths, polarizations, resolutions and digitizations shown in Table 2. Assumptions about multiple looks for the imaging radar and large calibration data loads for the microwave radiometer are also shown in the table. These assumptions are sufficiently accurate to scope the problem rather than be definitive at this time. The columns labeled wavelengths and polarizations show the number of different wavelengths and different polarizations at which data would be simultaneously recorded. Thus, for example, the IR radiometer would record data for two different polarizations at each of 10 different wavelengths giving a total of twenty channels of data. The column labeled digitizations indicates the number of bits recorded for each data sample. The column labeled resolutions shows the different possible resolutions being considered to show their effect on the data accumulation rate. The resolution of the altimeter varies depending on its operating mode. The choice of this value is not critical since the altimeter accumulates data at a very low rate compared with the rest of the instruments. Therefore, a value of 5 km has been rather arbitrarily assigned to altimeter resolution.

2.2 Coverage Model

For the purposes of this study, a rather simple coverage model is adequate to describe all the instruments. This model assumes that each instrument scans from side to side across the flight path in a raster like pattern with no gaps in the coverage. This is shown in Figure 3. Also shown are equations for the swath width and data rate in bits per kilometer along the flight path. This definition of data rate is more fundamental than a rate in bits per second since the latter would depend on aircraft velocity.

Table 2. Instrument Payload Complexity Assumptions

	Wavelengths	Polarizations	Resolutions	Special	Digitizations
Altimeter	1	1	5 km		10
Imaging Radar	2	1	25 m, 10 m	1, 4 looks	4, 10
Scatterometer	1	2	5 km, 1 km, 0.5 km		10
Microwave Radiometer	7	2	5 km, 1 km, 0.5 km	+50% for Calibration	10
IR Radiometer	10	2	5 km, 1 km, 0.5 km		10



H = Atitude (km)

C = Number of Data Channels

B = Bits Per Sample

ρ = Resolution Cell Size (km)

ϕ = Half-Angle Field of View

Swath Width = $2H \cdot \tan \phi$

Data Rate (Bits Per km) = $B \cdot C \cdot \frac{2H \cdot \tan \phi}{\rho^2}$

FIGURE 3. IDEALIZED COVERAGE MODEL

The swath widths which result for the various combinations of altitude and field of view are given in Table 3.

Table 3. Swath Widths Used to Determine Aircraft Requirements

Altitude, H	Half-Angle Field of View, ϕ	
	45^{o}	55^{o}
10,000 ft	3.3 n.mi. 6.1 km	4.7 n.mi. 8.7 km
30,000 ft	9.9 n.mi. 18.3 km	14.1 n.mi. 26.2 km
65,000 ft	21.4 n.mi. 39.7 km	30.5 n.mi. 56.6 km

2.3 Number of Aircraft Required

Using charts of the East Coast at a scale of 1,200,000:1 (16.5 n.mi. per inch) together with the swath widths shown in Table 3, flight paths were laid out to cover all bays and estuaries for each combination of altitude and field of view. By measuring the total length of the plotted paths, the number of flight miles necessary for a single coverage pass over the entire coast was computed. This procedure was repeated for the case of coverage out to 12 nautical miles. For the case of coverage out to 200 miles two different techniques were used. The first method was to determine the ocean surface area from the coast line out to 200 miles, divide this by the swath width to get an estimate of the flight miles necessary to cover this area and then add the number of miles of flight previously calculated for bays and estuaries above. The second method is based on the observation that a large rectangle 1300 n.mi. long by 230 n.mi. wide approximately covers the area in question. Dividing the area of this rectangle by the swath width yields an estimate of the total flight miles required. These two methods produce estimates which agree to within 10 per cent.

Table 4 summarizes the results of these computations. Two observations need to be made about the results. The first is that no overlapping of the swaths was assumed in arriving at these estimates. The amount of overlap necessary to insure that no coverage gaps occur due to navigation errors, irregular cross winds and other causes will depend on the type of aircraft, type of navigation system, altitude, speed and other factors. For purposes of approximate analysis a figure of about one nautical mile would be reasonable. Therefore, at the higher altitudes, where swath widths are 10 to 30 miles, allowing for overlap would not significantly change the results of the analysis. At 10,000 foot altitude, on the other hand, swath widths are only 3 to 5 miles. Therefore, allowing one mile of overlap could increase the required number of flight miles by 20 to 30 per cent. For this reason, the figures given in Table 4 for 10,000 foot altitude should be regarded as conservatively low.

A second observation about the figures given in Table 4 is in regard to the relative number of flight miles required for the different coverage widths. The differences between coverage of bays and estuaries only and coverage out to 200 miles is not as large as one might at first expect. The reason for this is that there are many bays and estuaries which extend inland for considerable distances. For example, Albermarle Sound and Pamlico Sound extend inland 80 miles from Cape Hatteras. Parts of Chesapeake Bay and Delaware Bay extend more than 100 miles from the shore. Reasonable flight paths to cover Cape Cod areas extend 65 miles inland. As a result, the amount of surface area which must be covered to observe all bays and estuaries is larger than one might expect.

Table 4. Summary of Total Flight Miles

	Altitude(ft)	Field of View(deg)	Flight Distance Miles (km)
Coverage of Bays and Estuaries Only			
	65,000 (20,000 m)	55	2,060 (3,810)
	65,000	45	2,420 (4,480)
	30,000 (9,000 m)	55	3,250 (6,020)
	30,000	45	5,380 (9,960)
	10,000 (3,000 m)	55	8,920 (16,520)
	10,000	45	12,740 (23,590)
Coverage to 12 Nautical Miles			
	65,000	55	2,550 (4,720)
	65,000	45	3,510 (6,500)
	30,000	55	5,350 (9,910)
	30,000	45	7,030 (13,020)
	10,000	55	15,740 (29,150)
	10,000	45	22,470 (41,610)
Coverage to 200 Nautical Miles			
	65,000	55	9,150 (16,950)
	65,000	45	13,040 (24,150)
	30,000	55	21,230 (39,320)
	30,000	45	30,300 (56,110)
	10,000	55	63,830(118,210)
	10,000	45	90,910(168,360)

To proceed from estimates of total flight miles required to estimates of the number of aircraft required takes only a few short steps. Knowing aircraft velocity gives total flight hours. Postulating some reasonable maintenance and spares policy leads directly from flight hours to aircraft numbers.

In order to make these evaluations, some specific types of aircraft suitable for coastal zone reconnaissance were examined. Their characteristics are listed in Table 5. Perhaps the most interesting figure in this table is the 460 lb payload of the U-2. The five instrument SEASAT payload will weigh over 570 lb plus the weight of the imagery radar antenna. Therefore a single U-2 will not be able to carry all five instruments. This offsets the advantage of high altitude flight which would otherwise permit a small number of U-2's to cover the large area required for coastal zone reconnaissance. The 6-1/2 to 8 hour range of cruise times, for all the aircraft are of interest too because they correspond closely with the maximum number of hours per day that an average airplane can be operated. 6-1/2 to 8 hours per day comes to 2400 to 2900 hours per year which is considered to be a heavy load. Thus, it is reasonable to expect that each aircraft will be able to make only one flight each day.

Of course, it will not be possible to gather data during the entire 6-1/2 to 8 hours of each flight. Time will be consumed in going from the base to the beginning of the data taking area and time will be consumed in returning at the end of the mission. Time is also required for such things as calibrating instruments and making turns from one data pass onto the next. For this analysis it has been assumed that, on the average, perhaps 70 to 85 percent of the flight time will be devoted to actual data taking.

A typical commercial airline spares policy is to have one spare airplane for every six required. Since commercial airline practice generally reflects the best possible use of equipment, this figure was used to determine the number of spare aircraft required for coastal zone reconnaissance. This results in an estimate which is on the optimistic side.

Putting all these factors together, the total number of aircraft required for twice daily coverage of the entire east coast can be computed from the equation

$$N = \left[2 \cdot (1.17) \cdot P \cdot \frac{M}{V \cdot (F \cdot T)} \right] \tag{1}$$

Table 5. NASA Remote Sensing Aircraft Characteristics

Aircraft Type	Typical Reconnaissance Altitude (feet)	Typical Reconnaissance Speed (knots)	Range (n.mi.)	Cruise Time (hr.)	Instrument Payload Weight (lb)
Lockheed NP-3A Orion	30,000 (9,000 m)	150-350 (280-650 km/hr)	2,000 (3,700 km)	6 1/2 - 7	5,000 (2,300 kg)
Lockheed NC-130B	30,000 (9,000 m)	150-330 (280-610 km/hr)	2,500 (4,600 km)	8	880 (400 kg)
Martin WB57F Canberra	40-60,000 (12-18,000 m)	400 (740 km/hr)	2,500 (4,600 km)	7	4,200 (1,900 kg)
Convair 990	30-40,000 (9-12,000 m)	480 (890 km/hr)	3,300 (6,100 km)	6 1/2	14,000 (6,400 kg)
Lockheed U-2	50-65,000* (15-20,000 m)	400 (740 km/hr)	2,500 (4,600 km)	6 1/2	460 (210 kg)

(Source of Data: "Guide to NASA's Earth Observation Aircraft Program Facilities")

*For Light Load

were M is the total flight mileage given in Table 4, V is the aircraft velocity given in Table 5, and T is the cruise time given in Table 5. F is a reduction factor varying from 0.70 to 0.85 to account for the fact that data is not taken during the entire mission. P is a payload factor which is two (2) for the U-2 and one (1) otherwise. The factor 1.17 reflects the spares policy, and the factor 2 reflects the fact that twice daily coverage is required but each aircraft can make only one flight per day. The brackets are used here simply as a reminder that N in an integer rounded off from the rational number within the brackets.

Figure 4 is a graphic aid for evaluating equation (1) for various parameter sets. The upper graph summarizes the flight mileages given in Table 4. It shows the flight mileages for different altitudes, fields of view and coverage requirements. The crosses which correspond to the data points given in the table, are connected by straight lines to allow interpolation to other altitudes. The lower graph is a plot of a compact version of equation (1), namely:

$$N = 2 \cdot (1.17) \cdot \frac{M}{D} \tag{2}$$

where D is the number of miles of data taken by each plane on each flight,

$$D = V \cdot (F \cdot T) \tag{3}$$

The payload factor P is not included. Therefore, the value of N read off the graph must be multiplied by 2 in the case of the U-2. To use Figure 4 enter at the desired altitude on the upper graph and proceed horizontally to the line corresponding to the desired coverage band and field of view. From here move vertically down onto the second graph until reaching the line corresponding to the desired value of D. Then move horizontally to the left and read N. (For the U-2, multiply this value by 2).

Table 6 shows values of N for various specific aircraft types. The ranges of values come from assigning values between 0.70 and 0.85 to F to account for the fact that data is not taken during an entire mission. Drawing conclusions from these data relative to preferred aircraft is not within the scope of this task.

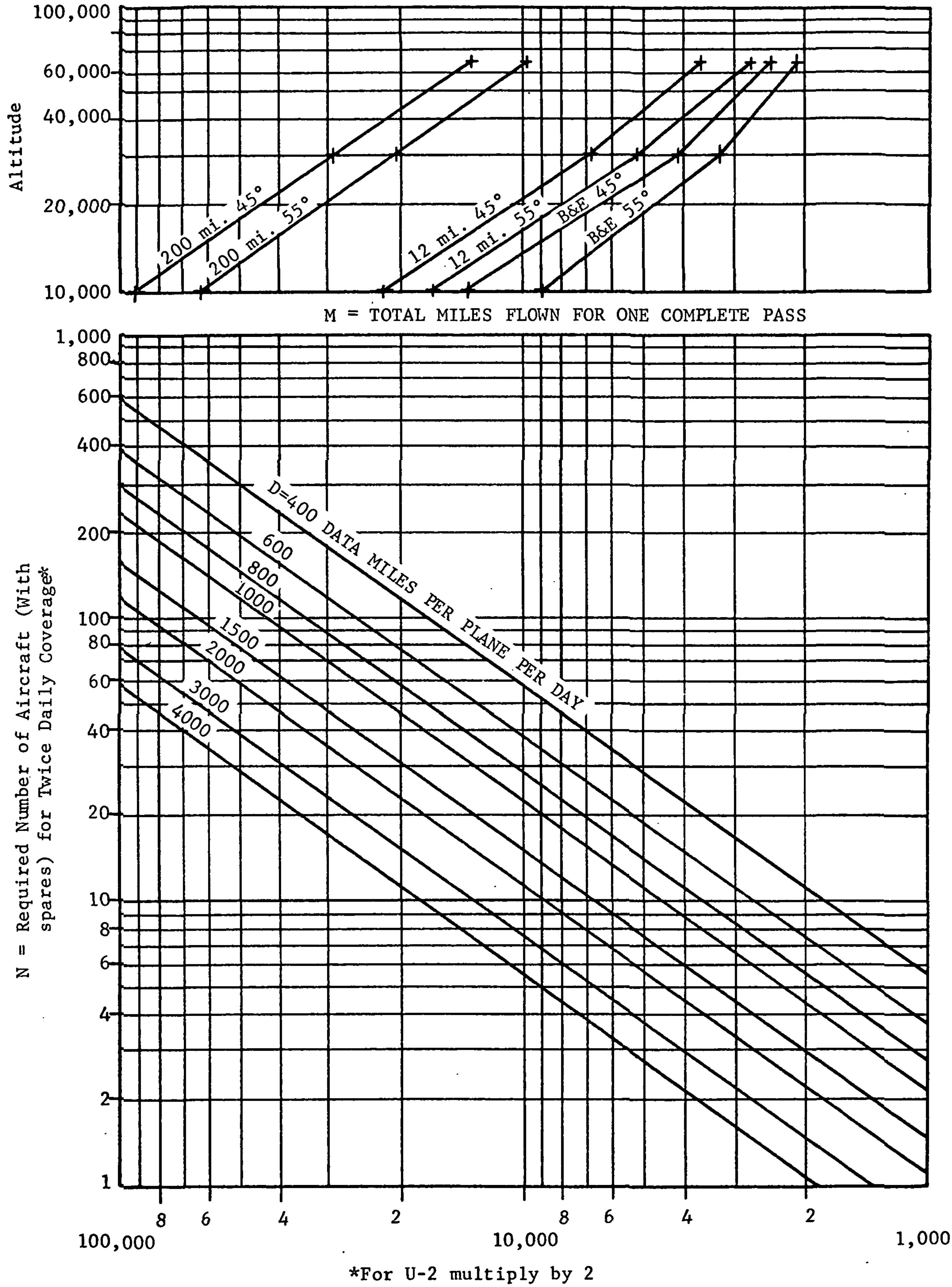


FIGURE 4. AIRCRAFT REQUIREMENTS GRAPH

Table 6. Numbers of Aircraft Required fcr Specific Aircraft

Aircraft	Altitude (feet)	Speed (knots)	Cruise Time (hours)	FOV	Number of Aircraft Required for: Bays and Estuaries	To 12 Miles	To 200 Miles
Lockheed U-2	65,000 (20,000 m)	400 (740 km/hr)	6.5	45^o	6-8	8-10	30-36
				55^o	6	6-8	20-26
Lockheed NP-3A	30,000 (9,000 m)	350 (650 km/hr)	6.5	45^o	5-6	9-11	38-45
				55^o	4-5	7-8	27-32
Convair 990	40,000 (12,000 m)	480 (890 km/hr)	6.5	45^o	3-4	5-6	22-25
				55^o	3	4-5	15-18
Martin WB57F	60,000 (18,000 m)	400 (740 km/hr)	7	45^o	3	4-5	15-18
				55^o	3	3	10-13
Lockheed NC-130B	30,000 (9,000 m)	330 (610 km/hr)	8	45^o	5	7-9	32-38
				55^o	4	6-7	23-26

2.4 Data Accumulation Rates

Estimation of the data accumulation rates is relatively simple and straightforward. In Figure 3 the data rate, R, for each instrument in bits per kilometer along the flight path was given as

$$R = B \cdot C \cdot \frac{2\ H \tan \phi}{\rho^2} \qquad (3)$$

where

B = bits per sample

C = number of channels of data (= number of frequencies x number of polarizations)

H = aircraft altitude (km)

ϕ = half-angle field of view

ρ = resolution (km)

For the imaging radar this rate must be multiplied by the number of looks. For the microwave radiometer the rate must be multiplied by 1.5 to account for the calibration data load.

If the resulting data rate, converted to bits per nautical mile, is multiplied by the total flight miles for a given coverage area, the result is the total number of bits accumulated for the whole area. For the imaging radar, Table 7, generated by computer, shows the total number of bits for each of the three coverage widths for each combination of altitude, field of view, resolution, quantization level and number of looks.

The total number of bits should be relatively independent of aircraft altitude and field of view. A given sample cell size (resolution) and number of bits per sample cell should result in a constant number of bits for a constant size area. The table confirms this; comparing, for example, case one with case 17 shows that, while the altitudes are different, the numbers of bits are nearly equal beacuse RHO, L and Q are the same. Slight variations are due to different choices of flight path. Other factors may cause larger variations. For example, case 41 has the same values of RHO, L, and Q, as case one but the number of bits for the bays and estuaries

TABLE 7. TOTAL AMOUNT OF DATA GENERATED BY IMAGING RADAR

SYNTHETIC APERTURE RADAR   2 CHANNELS

R = DATA RATE IN BITS PER N. MI. ALONG A SINGLE PASS
Q = NUMBER OF BITS PER SAMPLE
RHO = RESOLUTION IN METERS
ALT = ALTITUDE IN FEET
FOV = HALF ANGLE FIELD OF VIEW IN DEG
L = NUMBER OF LOOKS

								TOTAL BITS FOR	
	ALT	FOV	RHO	L	Q	R	B AND E	12 MILES	200 MILES
1	10000.	45.	25.0	1.	4.	144509.	1.835E+09	3.251E+09	1.314E+10
2	10000.	45.	25.0	1.	10.	361273.	4.588E+09	8.129E+09	3.284E+10
3	10000.	45.	25.0	4.	4.	578037.	7.341E+09	1.301E+10	5.254E+10
4	10000.	45.	25.0	4.	10.	1445092.	1.835E+10	3.251E+10	1.314E+11
5	10000.	45.	10.0	1.	4.	903183.	1.147E+10	2.032E+10	8.210E+10
6	10000.	45.	10.0	1.	10.	2257956.	2.868E+10	5.080E+10	2.052E+11
7	10000.	45.	10.0	4.	4.	3612730.	4.588E+10	8.129E+10	3.284E+11
8	10000.	45.	10.0	4.	10.	9031825.	1.147E+11	2.032E+11	8.210E+11
9	10000.	55.	25.0	1.	4.	206381.	1.857E+09	3.240E+09	1.317E+10
10	10000.	55.	25.0	1.	10.	515951.	4.644E+09	8.100E+09	3.292E+10
11	10000.	55.	25.0	4.	4.	825522.	7.430E+09	1.296E+10	5.267E+10
12	10000.	55.	25.0	4.	10.	2063805.	1.857E+10	3.240E+10	1.317E+11
13	10000.	55.	10.0	1.	4.	1289878.	1.161E+10	2.025E+10	8.229E+10
14	10000.	55.	10.0	1.	10.	3224696.	2.902E+10	5.063E+10	2.057E+11
15	10000.	55.	10.0	4.	4.	5159513.	4.644E+10	8.100E+10	3.292E+11
16	10000.	55.	10.0	4.	10.	12898783.	1.161E+11	2.025E+11	8.229E+11
17	30000.	45.	25.0	1.	4.	433528.	1.864E+09	3.035E+09	1.314E+10
18	30000.	45.	25.0	1.	10.	1083819.	4.660E+09	7.587E+09	3.284E+10
19	30000.	45.	25.0	4.	4.	1734110.	7.457E+09	1.214E+10	5.254E+10
20	30000.	45.	25.0	4.	10.	4335276.	1.864E+10	3.035E+10	1.314E+11
21	30000.	45.	10.0	1.	4.	2709548.	1.165E+10	1.897E+10	8.210E+10
22	30000.	45.	10.0	1.	10.	6773869.	2.913E+10	4.742E+10	2.052E+11
23	30000.	45.	10.0	4.	4.	10838190.	4.660E+10	7.587E+10	3.284E+11
24	30000.	45.	10.0	4.	10.	27095476.	1.165E+11	1.897E+11	8.210E+11
25	30000.	55.	25.0	1.	4.	619142.	2.043E+09	3.343E+09	1.313E+10
26	30000.	55.	25.0	1.	10.	1547854.	5.108E+09	8.358E+09	3.281E+10
27	30000.	55.	25.0	4.	4.	2476566.	8.173E+09	1.337E+10	5.250E+10
28	30000.	55.	25.0	4.	10.	6191416.	2.043E+10	3.343E+10	1.313E+11
29	30000.	55.	10.0	1.	4.	3869635.	1.277E+10	2.090E+10	8.204E+10
30	30000.	55.	10.0	1.	10.	9674087.	3.192E+10	5.224E+10	2.051E+11
31	30000.	55.	10.0	4.	4.	15478540.	5.108E+10	8.358E+10	3.281E+11
32	30000.	55.	10.0	4.	10.	38696349.	1.277E+11	2.090E+11	8.204E+11
33	65000.	45.	25.0	1.	4.	939310.	2.254E+09	3.288E+09	1.221E+10
34	65000.	45.	25.0	1.	10.	2348275.	5.636E+09	8.219E+09	3.053E+10
35	65000.	45.	25.0	4.	4.	3757239.	9.017E+09	1.315E+10	4.884E+10
36	65000.	45.	25.0	4.	10.	9393098.	2.254E+10	3.288E+10	1.221E+11
37	65000.	45.	10.0	1.	4.	5870686.	1.409E+10	2.055E+10	7.632E+10
38	65000.	45.	10.0	1.	10.	14676716.	3.522E+10	5.137E+10	1.908E+11
39	65000.	45.	10.0	4.	4.	23482746.	5.636E+10	8.219E+10	3.053E+11
40	65000.	45.	10.0	4.	10.	58706864.	1.409E+11	2.055E+11	7.632E+11
41	65000.	55.	25.0	1.	4.	1341473.	2.817E+09	3.488E+09	1.234E+10
42	65000.	55.	25.0	1.	10.	3353684.	7.043E+09	8.720E+09	3.085E+10
43	65000.	55.	25.0	4.	4.	5365894.	1.127E+10	1.395E+10	4.937E+10
44	65000.	55.	25.0	4.	10.	13414734.	2.817E+10	3.488E+10	1.234E+11
45	65000.	55.	10.0	1.	4.	8384209.	1.761E+10	2.180E+10	7.713E+10
46	65000.	55.	10.0	1.	10.	20960522.	4.402E+10	5.450E+10	1.928E+11
47	65000.	55.	10.0	4.	4.	33536836.	7.043E+10	8.720E+10	3.085E+11
48	65000.	55.	10.0	4.	10.	83842090.	1.761E+11	2.180E+11	7.713E+11

case is significantly higher for case 41. The reason for this is that at high altitude and large field of view the swath width is wider than necessary for coverage of bays and estuaries along most of the southern half of the East Coast. This results in more than the minimum amount of data being generated.

Table 8 shows similar results for the scatterometer. Similar tables for the other instruments were not generated since the data rates are quickly derivable from Table 8. Total bits for the IR radiometer and the microwave radiometer are constant multiples of the values for the scatterometer since the only differences are in the number of channels and the calibration data load factor. For the altimeter, the number of bits is very small and is simply equal to the total flight distance divided by the resolution and multipled by the number of bits per sample.

Because the total number of bits is essentially independent of the altitude and field of view, the information in Tables 7 and 8 can be considerably compressed. Table 9 shows the total number of bits per day (twice the number of bits per pass) for various implementations of each instrument. Note that since the altimeter measures a function along a line rather than over an area, its bit accumulation rate is a function of altitude and field of view because these parameters determine the number of flight miles necessary to cover a given area. Therefore, in the table, a range of values is given for this instrument. Note also that the total number of bits is measured in billions for the imaging radar but only in millions or thousands for the other instruments.

Millions of bits and billions of bits are numbers which, in themselves, may not convey a great deal of meaning. To develop an apprecia- tion of how much data this really is, it is worthwhile to compute the number of reels of computer tape it might take to store this amount of data. A standard size reel of computer tape as used in many data processing facilities is 10-1/2 inches in diameter and contains 2400 feet of 1/2 inch wide tape. Densities at which data is written vary widely but an example which could be considered as moderate, i.e., neither unusually low nor unusually high, is 800 bits per inch on each of 6 parallel data tracks (a seven track tape with one parity bit). This is a total of 4800 bits per inch. Actually, the average density over the entire tape is not this high due to the

TABLE 8. TOTAL AMOUNT OF DATA GENERATED BY SCATTEROMETER

SCATTEROMETER 2 CHANNELS

R = DATA RATE IN BITS PER N. MI. ALONG A SINGLE PASS
Q = NUMBER OF BITS PER SAMPLE
RHO = RESOLUTION IN KM
ALT = ALTITUDE IN FEET
FOV = HALF ANGLE FIELD OF VIEW IN DEG
F = CALIBRATION DATA LOAD FACTOR

							TOTAL BITS FOR		
	ALT	FOV	RHO	Q	F	R	B AND E	12 MILES	200 MILES
1	10000.	45.	5.0	10.	1.0	9.	1.147E+05	2.032E+05	8.210E+05
2	10000.	45.	1.0	10.	1.0	226.	2.868E+06	5.080E+06	2.052E+07
3	10000.	45.	0.5	10.	1.0	903.	1.147E+07	2.032E+07	8.210E+07
4	10000.	55.	5.0	10.	1.0	13.	1.161E+05	2.025E+05	8.229E+05
5	10000.	55.	1.0	10.	1.0	322.	2.902E+06	5.063E+06	2.057E+07
6	10000.	55.	0.5	10.	1.0	1290.	1.161E+07	2.025E+07	8.229E+07
7	30000.	45.	5.0	10.	1.0	27.	1.165E+05	1.897E+05	8.210E+05
8	30000.	45.	1.0	10.	1.0	677.	2.913E+06	4.742E+06	2.052E+07
9	30000.	45.	0.5	10.	1.0	2710.	1.165E+07	1.897E+07	8.210E+07
10	30000.	55.	5.0	10.	1.0	39.	1.277E+05	2.090E+05	8.204E+05
11	30000.	55.	1.0	10.	1.0	967.	3.192E+06	5.224E+06	2.051E+07
12	30000.	55.	0.5	10.	1.0	3870.	1.277E+07	2.090E+07	8.204E+07
13	65000.	45.	5.0	10.	1.0	59.	1.409E+05	2.055E+05	7.632E+05
14	65000.	45.	1.0	10.	1.0	1468.	3.522E+06	5.137E+06	1.908E+07
15	65000.	45.	0.5	10.	1.0	5871.	1.409E+07	2.055E+07	7.632E+07
16	65000.	55.	5.0	10.	1.0	84.	1.761E+05	2.180E+05	7.713E+05
17	65000.	55.	1.0	10.	1.0	2096.	4.402E+06	5.450E+06	1.928E+07
18	65000.	55.	0.5	10.	1.0	8384.	1.761E+07	2.180E+07	7.713E+07

Table 9. Bits Per Day for Each Instrument

Imaging Radar

Resolution (m)	Looks	Bits per Sample	Total Bits Per Day (x 10^9): Bays and Estuaries	Total Bits Per Day (x 10^9): To 12 Miles	Total Bits Per Day (x 10^9): To 200 Miles
25	1	4	4	7	30
25	1	10	9	20	70
25	4	4	10	30	100
25	4	10	40	70	300
10	1	4	20	40	200
10	1	10	60	100	400
10	4	4	100	200	700
10	4	10	200	400	2000

Scatterometer

Resolution (km)	Total Bits Per Day (x 10^6): Bays and Estuaries	Total Bits Per Day (x 10^6): To 12 Miles	Total Bits Per Day (x 10^6): To 200 Miles
5	.2	.4	2
1	6	10	40
0.5	20	40	200

Table 9. Bits Per Day for Each Instrument (Continued)

Microwave Radiometer

Resolution (km)	Total Bits Per Day (x 10^6) Bays and Estuaries	To 12 Miles	To 200 Miles
5	2	4	20
1	60	100	400
0.5	200	400	2000

IR Radiometer

Resolution (km)	Total Bits Per Day (x 10^6) Bays and Estuaries	To 12 Miles	To 200 Miles
5	2	4	20
1	60	100	400
0.5	200	400	2000

Altimeter

Total Bits Per Day (x 10^3) Bays and Estuaries	To 12 Miles	To 200 Miles
7-50	10-80	40-400

presence of inter-record gaps, end-of-record marks and other housekeeping details. But for the sake of simplicity, 4800 bits per inch can be used as a representative density. The capacity of a single tape is then $C = (2400 \text{ ft}) \times (12 \frac{\text{in}}{\text{ft}}) \times (4800 \frac{\text{bits}}{\text{in}}) = 1.4 \times 10^8$ bits. Thus, for coverage of bays and estuaries alone the imaging radar would generate enough data to fill a minimum of 28 reels of tape each day. With better resolution and finer quantization this number could go up to more than 1400 reels. For coverages out to 200 nautical miles with 10 meter resolution, 10 bits per sample and 4 looks, the number would be more than 14,000 reels of tape.

Of course, the other instruments are not nearly so bad. For all other instruments combined the figure for bays and estuaries would range from three hundredths of a reel per day to 3 reels per day depending on resolution. For coverage out to 200 miles between three tenths of a reel and 30 reels would be required.

It should be re-emphasized that many different recording densities exist for magnetic tapes and so the figures given here should only be used to get a rough idea of the magnitude of the data handling problem. The important figures are the actual numbers of bits given in Table 9.