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The Logistics of Oil Spill Dispersant Application

Volume II: Application Techniques, Stockpiling, Dispersant Selection, Strategies

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16. Abstract

The use of chemicals for oil spill dispersal, while not presently widespread in the U.S., would have implications for the U.S. Coast Guard's Marine Environmental Protection program. This report explores the logistics of oil dispersant application by the U.S. Coast Guard.

Volume I: Logistics-Related Properties of Oil Spill Dispersants

Data were reviewed for the 13 dispersants for which data had been submitted to the EPA as of October 1979. Manufacturer's data and published test results were also examined and information summarized with regard to classification, handling and storage, application, availability and cost.

Volume II: Application Techniques, Stockpiling, Dispersant Selection, Strategies

Formulae and charts are developed for analyzing single and multiple-pass application; factors in stockpiling, and present inventories are examined; the factors in dispersant selection from Volume I are summarized. Six operational strategies, consisting of choices of vehicles, stockpiles and dispersant, are formulated and evaluated.

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PREFACE

The use of chemicals for the dispersal of oil spilled on water has been the subject of discussion (and of disagreement) since their first major use in the Torrey Canyon disaster in 1967. The net adverse ecological effects produced by dispersants in that spill raised serious questions about their use. Although dispersant formulations have since been developed that are more effective and less toxic than those used on the Torrey Canyon spill, their use is not universally accepted. In the United States, in particular, a cautious approach has been taken; use of dispersants is governed by the National Oil and Hazardous Substances Pollution Contingency Plan, which requires that approval be obtained from the Regional Response Team before chemical dispersion is undertaken. This approval has been sought and employed in relatively few cases in the United States compared to other countries.

Despite their infrequent use at present in the United States, the implications of chemical dispersion of oil would be substantial for the US Coast Guard if it become common. Accordingly, the US Coast Guard Office of Marine Environment and Systems (USCG/G-W) requested the Transportation Systems Center to analyze the logistics of handling, stocking, transporting and applying of chemical oil dispersants. The study was carried out by the Transportation Systems Center Office of Air and Marine Systems (DOT/DTS-500) in Fiscal Year 1980.

The project was initiated under the sponsorship of CDR J. Valenti, USCG/GWEP, and completed under CDR. R. Rufe Jr. of the Pollution Response Branch, Environmental Response Division. Technical guidance and assistance were provided by LCDR W. Jurgens and CDR J. Paskowich of the US Coast Guard. Numerous Coast Guard personnel provided assistance and information, as did many individuals in the Environmental Protection Agency and industry.

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INTRODUCTION

Research and discussion concerning the use of chemicals for the treatment of oil spills has risen substantially in the last three years.[1] While it is still not clear that the use of dispersants in US waters will be expanded,[2] it must be assumed that their widespread use would have important impacts on the Coast Guard's Marine Environmental Response Program. These impacts would occur in the areas of operational procedures, programs, planning, funding, and effectiveness. In order to assess these impacts the Coast Guard has initiated a study of the logistic requirements of oil spill dispersal by chemicals. The first part of the study, covered in the Volume I, deals with the classification of dispersants,[3] storage and handling properties, characteristics, availability, and cost. This volume deals with techniques of dispersant application, the factors in dispersant stockpiling, selection of dispersants and the formulation of over-all strategies. In the final section of this volume the methods developed are synthesized into a set of recommendations for the Coast Guard in acquiring, stockpiling, transporting, and applying dispersants for oil spills in U.S. waters.

It must be noted that this study does not deal with the very important question of whether dispersants should be used in any given spill case. The decision to do so must be based on the judgment of the EPA member of the Regional Response Team, in consultation with appropriate state and local agencies, that their use would result in the least overall environmental damage,

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[1] See, for example, the Introduction of Reference 1. The number of papers dealing with dispersants in the 1977 and 1979 Conferences on the Prevention and Control of Oil Spills was about double that in the 1973 and 1975 meetings.

[2] After their use in the Santa Barbara Spill in 1969, dispersants were not used under Annex X of the National Contingency plan until 1978 (dredge Pennsylvania) and again in 1979 (Sea Speed Arabia).

[3] Oil collecting agents and biological additives are excluded.

DISPERSANT APPLICATION TECHNIQUES

The application of a dispersant to the slicks resulting from an oil spill usually involves repeated round trips from the dispersant supply base to the spill area by aircraft or vessels specially outfitted to apply the dispersant. The speed and efficiency with which the operation is completed depends on several parameters, including the speed of the vehicles, the size and shape of the slicks, the distance from supply base to the spill, and the time required to reload the vehicles. It is important for planning purposes to estimate the time and cost of dispersing a given amount of spilled oil as a function of these parameters. Of special interest is the comparison of time and cost for aircraft as opposed to vessel.

Several analyses of dispersant application have been published. (References 1, 2, 3.) Hildebrand et al. treated a problem of concern to the Canadian Environmental Protection Service, namely, that of responding to a spill in the southern Beaufort Sea. Lindblom has developed extensive tables for several aircraft, and Steelman has analyzed both workboats and aircraft in two spill scenarios, using methods that were verified by actual experience at the IXTOC I blowout. The analysis to follow adapts the extensive work of these three sources to the particular requirements of the U.S. Coast Guard.

1. SINGLE PASS ANALYSIS

A single pass of a vehicle dispensing a chemical over a uniform slick may be described approximately by the equations

$$t = \frac{1}{10} V/A \qquad (1)$$

$$a = 10{,}000\ te \qquad (2)$$

$$d = \frac{1}{600}\ v\ w\ a \qquad (3)$$

The relations (1), (2) and (3) are summarized in the chart in Figure 1. This chart may be used to plan a pass over a uniform oil slick by any of the commonly employed vessels or aircraft.

Example: A large harbour slick is to be dispersed by work-boat. The amount of oil is known to be 100 metric tons (about 30,000 gallons). The size is estimated to be about 1n. mi. long and 0.6 n. mi. wide (22 million sq. ft. or 200 hectares). The dispersant effectiveness ratio is assumed to be 1:10 when employed on the crude involved. The work boat swath width is 20 meters, and its top speed is 20 knots or 37 km/hr. Its pumps can be adjusted to put out from 5 to 25 gallons/minute (19 to 95 liters/minute).

The chart in Figure 1 is entered at the lower right with the slick area; 200 hectares. One proceeds then horizontally to the left, reaching the diagonal line representing the (known) amount to be dispersed, 100 tons, and thence up vertically along the slick thickness line (read off at the top as .05 mm), to the diagonal line corresponding to the (known) effectiveness ratio, 1:10. The dashed line then goes horizontally to the left at the resultant areal density (50 liters/hectare) to the diagonal line for the swath width, 20 meters. The dashed line then descends to the lower left quadrant to a diagonal line representing the pumping or dosage rate. If a pumping rate of 50 liters/minute is selected, then it is seen that the work boat must travel at 30 kilometers/hour (16 knots). Alternately, one may select the vessel speed (say, 15 kilometers/hour or 8.1 knots) and from the intersection of the corresponding horizontal line with the vertical dashed line, determine that a dosage rate of 15 liters/minute would be required.

Since the dispersant to oil ratio is taken to be 1:10 for full dispersion, 10 tons of dispersant will be required to treat the 100 tons of oil. At 15 liters/minute (3.96 US gallons or .0132 tons/minute) it will take about 6.3 vessel-hours, of spraying. Allowing a maneuvering efficiency of 0.25 gives on-scene operating times of 50.4 vessel-hours or 25.2 vessel-hours, depending on the dosage rate selected.

Note that spills of larger area and volume than shown in Figure 1 may be accommodated by multiplying by 10 the numbers for slick area and spill volume shown in the lower right quadrant.

2. MULTIPLE PASS ANALYSIS

Most oil spills must be treated by several passes of the vehicle, for several reasons. First is the geometry of the slick or slicks. This geometry is seldom suited to a single pass, so that a series of passes must be devised to make up a spray pattern that fits the particular slick geometry and spraying priorities of the spill. Secondly, the vehicle must return to its operations base for restocking dispersant and fuel. Finally, since spraying can be conducted effectively only in daylight, several days of operation may have to be allowed for. The objective here is to determine the effect of these three restrictions on the total time required to treat a given spill, or, what is equivalent, on the total amount of oil that can be treated in a given time.

2.1 Effect of Spray Pattern

A spray pattern comprises a series of passes over one or more slicks by the spraying vehicle. The time required to execute the pattern depends on the total area sprayed, the speed of the vehicle(s) in spraying, turning, and repositioning, the turning radius, the mean slick length, slick continuity, and the swath width.

Figure 2 illustrates five spray patterns. The same patterns also apply if the sections of slick shown in this figure are discontinuous, as shown explicitly in pattern 3. In that case, the spray would be turned off as the vehicle traverses segments of open water, but the vehicle would not change speed or course. The first two patterns are for aircraft application, the latter two are for vessel application. Pattern 3 may be adapted for either. These patterns are related to these for SAR (App. I).

Aircraft patterns are more restricted than vessel patterns because they require a much larger minimum turn radius (typical values being 0.5 to 1.0 n.mi.). Also, aircraft patterns must take account of the wind. Crosswind spraying is generally found to lead to a less uniform cover of dispersant. Spraying into or with the wind leads to more uniform results, but the airspeed must be adjusted so as to give the proper ground speed, i.e., the parameter v in the single pass analysis is ground speed. Pattern 1 provides spray runs in one direction only, which direction can be chosen to be parallel or anti-parallel to the wind vector. Pattern 2 provides runs both with and against the wind. Pattern 2 is more dif-

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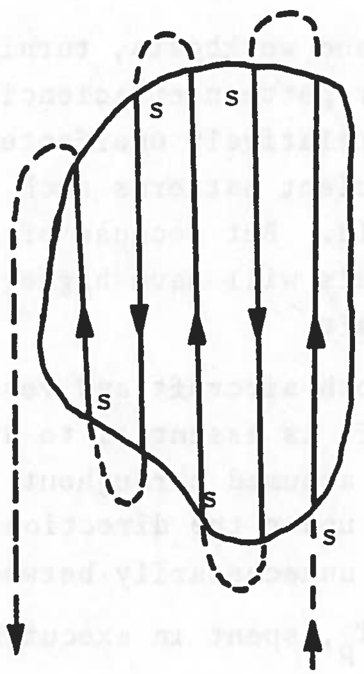

s = Start of pass

FIGURE 2. TYPICAL SPRAY PATTERNS (CONTINUED)

TABLE 1. TERMS IN EQUATION (4) FOR TOTAL TIME IN SPRAY PATTERN

Pattern/Vehicle	T_s	T_x	T_t	T_r
1/Fixed Wing	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(2\pi R+w')}{v_t}$	$\frac{A_p}{w}\frac{10}{v_r}+\frac{L_p}{v_r}$
2/Fixed Wing	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+w')}{v_t}$	
3/Fixed Wing, Helicopter, or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+4\phi R)}{v_t}$	
4/Helicopter or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$		
5/Helicopter or Vessel	$\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{w}\frac{10}{v_x}$	$\frac{n_p(\pi R+4\phi R)}{v_t}$	
6/Several Vessels	$\frac{1}{n_V}\frac{A_s}{w}\frac{10}{v_s}$	$\frac{A_p-A_s}{n_V w}\frac{10}{v_x}$		

A_s = area of slick within the pattern, hectares

w = swath width, meters

v_s = vehicle speed while spraying, kilometers/hr

A_p = area of pattern, hectares (See Figure II-3)

v_x = vehicle speed in pass, not spraying, kilometers/hr

R = vehicle turning radius, kilometers

v_r = vehicle speed while repositioning to next pass, kilometers/hr

L_p = length of spray pattern, kilometers (See Figure 3)

v_t = vehicle speed in turning, kilometers/hr

w' = swath width, kilometers

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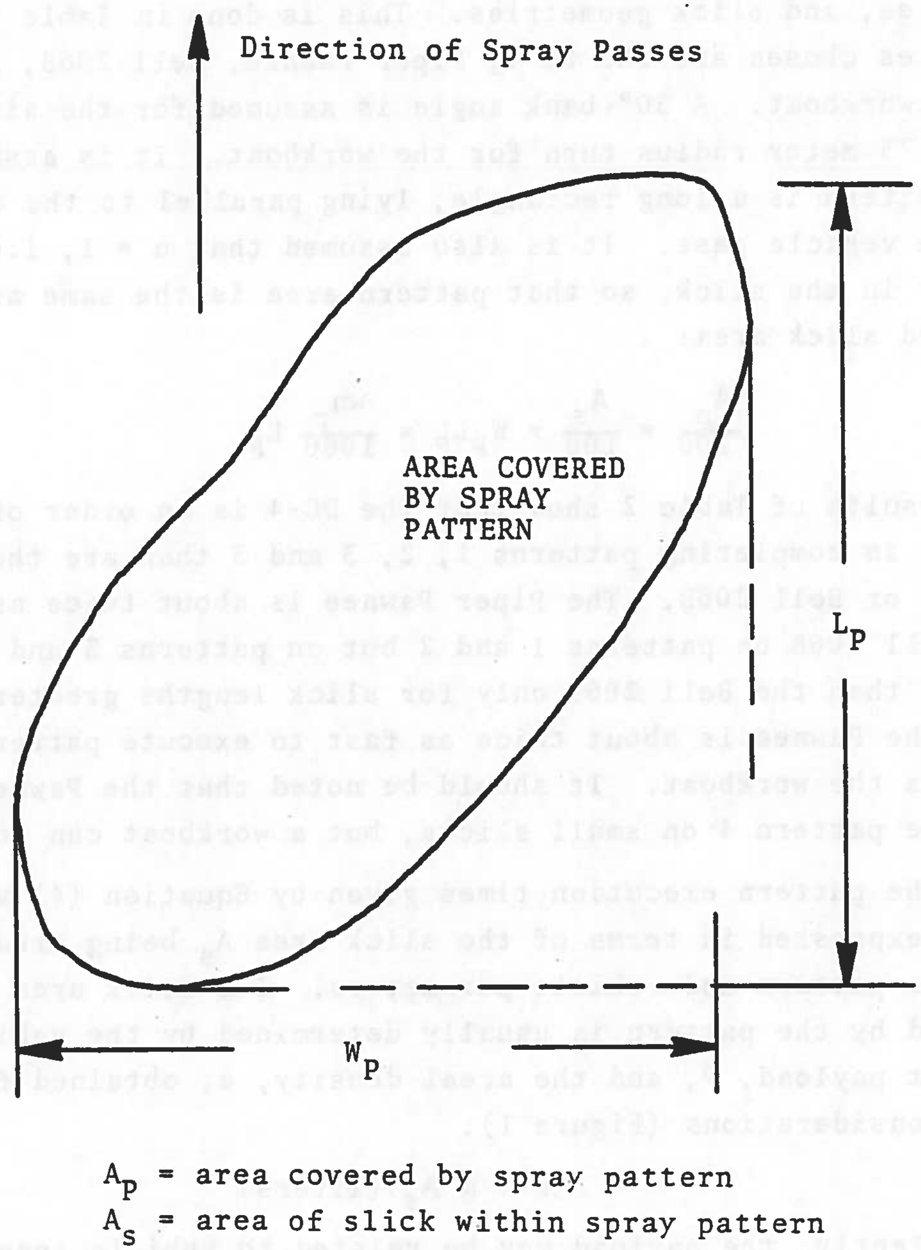

FIGURE 3. DIMENSIONS OF AREA COVERED BY SPRAY PATTERN

TABLE 2. PATTERN TIME PER UNIT AREA OF SLICK FOR TYPICAL VEHICLES AND PATTERNS

Pattern #1	T_p/A_p (hours/hectare)
DC-4	$.00142 + .0027/L_p + .000034/W_p$
Piper Pawnee	$.00950 + .010/L_p + .000067/W_p$
Bell 206B	$.01880 + .011/L_p + .00010/W_p$
Pattern #2	
DC-4	$.00074 + .0014/L_p$
Piper Pawnee	$.00512 + .0050/L_p$
Bell 206B	$.01100 + .0059/L_p$
Patterns #3, #5	
DC-4	$.00074 + .0031/L_p$
Piper Pawnee	$.00512 + .0115/L_p$
Bell 206B	$.01100 + .0087/L_p$
Workboat	$.02800 + .0219/L_p$

Pattern #4		Pattern #6
Bell 206B	.0110	
WorkBoat	.0278	$.0278/n_V$

Data Employed to calculate T_p/A_p from formulas of Table 1:

Vehicle	$\frac{w}{m}$	$\frac{v_s}{km/h}$	$\frac{R}{km}$	$\frac{v_r}{km/h}$	$\frac{v_t}{km/h}$
DC-4	49	277	1.18	294	277
Piper Pawnee	15	130	.31	150	130
Bell 206B	16	56	.043	80	16
Workboat	20	18	.075	-	12

Table 3 lists the operating parameters for several vehicles. These parameters affect the single pass operations discussed previously, round-trip operations, and daily operations to be discussed next.

2.3 Effect of Daily Operations

It is common to allow a 10-hour day for dispersant operations, resulting in an integral number of sorties per day for each vehicle. Early morning and late evening on clear days are hampered by a low sun angle, which makes it more difficult to detect the boundaries of the slick from the spotter aircraft. Nevertheless, these hours are still useful for transit from operations base to spill.

For each aircraft there is a trade-off between dispersant payload and maximum value of D. The larger the payload, including tanks, the less fuel can be loaded, and the shorter the range. Fuel consumption depends on air speed, altitude and payload. The total fuel consumed in a round-trip is C_F.

$$C_F = c_T\, T_T + c_s\, T_s + c_t T_t + c_r\, T_r + c_s\, T_x$$

where c_T, c_s, c_t, c_r are fuel consumption rates in liters/hour for transit, spraying, turning and repositioning. The total C_F is divided into the useable fuel load, and the quotient rounded down to the next integer, to determine the maximum number of round trips between refuelings. The useable fuel load equals the maximum gross take-off weight minus aircraft operating weight, fuel reserve, payload, and crew weight.

It is common for medium and large workboats to carry enough fuel for several days. Many small workboats can carry enough fuel for at least one day's operation. Therefore most vessels have $T_F = T_{FD}$ on all round-trips, i.e, refurbishment time is determined by dispersant refill time rather than refueling time, because refueling can take place overnight.

TABLE 3. TYPICAL OPERATING PARAMETERS FOR AIRCRAFT AND VESSELS IN DISPERSANT APPLICATIONS (CONT.)

	DC-4	CL-215	Pawnee	HH3
P	9460	5300	375-560	1500
p	1980-2270	1500	300-340	150
T_{FD}	.25-.33	.25-.33	.16-.25	.25
T_{FF}	.40-.50	.40-.50	.33-.50	20
v_s	260-295	195-240	110-150	65.
v_T	350	300	150	
v_t	260	195	110	0-65.
v_r	295	240	150	
R	.92	.52	.17	0.-.058
w	55 (4)	35	20	16
T_D	4.2-5.0	3.5	1.1-1.9	10.

	Bell 206B	Large WB	Medium WB	Small WB
P	172	38000.	7500	756
p	150	95	32	25
T_{FD}	.25	2.0	1.0	0.5
T_{FF}	.25	3.0	1.5	1.0
v_s	65.	12.0	7.0	7.0
v_T	160	22.	14.0	12.0
v_t	0-65.	12.0	7.0	7.0
v_r	160.	22.0	14.0	12.0
R	0.-.058	.075	.035	.020
w	38	20	7	3
T_D	1.1	400.	234.	30.

dispersant applied, rather than amount of oil treated. The latter depends on the effectiveness ratio, a highly variable quantity that is influenced by many factors other than the application vehicle. Estimation of the effectiveness ratio to be expected from a particular combination of dispersant, oil type and condition, temperature, agitation level, and application technique will be discussed in subsequent parts of this report.

3.2 Parameters Affecting Performance

The performance measures above are influenced by several variables, only some of which are taken into account here. Of those that are not here quantified, one has:

(1) Availability: This includes not only availability of a sufficent number of vehicles, but also of adequate crews and support equipment and fuel, as well as the proximity of a suitable operations base.

(2) Response Time: This is the time required to assemble the vehicles, crews, and support equipment at the operations base and prepare them for the mission.

(3) Suitability for selected dispersant: The application vehicle selection must be coordinated with the selection of dispersant; some dispersants require sea-water eduction systems, (not practical for aerial use) others require agitation. The suitability of a dispersant to a particular application method, moreover, cannot be inferred from its type (i.e., hydrocarbon-based, aqueous-based, or concentrate), but must be determined for each product separately.

(4) Safety of vehicles and crews: Small work boats are unsuitable for operation offshore under severe weather conditions. Large fixed wing aircraft cannot be safely operated at low levels near shoreline obstructions. Other conditions may preclude certain vehicles from use.

TABLE 4A. VEHICLE-SPECIFIC VALUES EMPLOYED TO CALCULATE PERFORMANCE MEASURES

Variable Name	Units	DC-6	DC-4	CL215	Pawnee
Pattern Number	Figure 2	1	1	1	1
Dispersant payload	liters	13,250	9,460	5,300	560
Max pumping rate	liters/minute	2,850	2,270	1,500	340
Dispersant refill time	hours	.29	.29	.29	.205
Fuel refill time	hours	.45	.45	.45	.415
Operating time per refuelling	hours	5.5	5.5	4.0	2.5
Swath width	meters	55	55	35	20
Turning radius	kilometers	.92	.92	.52	.17
Spraying speed	km/hour	278	278	218	130
Transit speed	km/hour	390	350	300	150
Turning speed	km/hour	260	260	195	110
Repositioning speed	km/hour	325	295	240	150

TABLE 4B. VEHICLE SPECIFIC OPERATING COSTS

Vehicle Type	Operating Cost	Retainer Cost	Fuel Consumption	Data Source
DC-6B	$1650/hr	$3800/day	(1)	a.
DC-4	1200/hr	120K/yr	(1)	b.
CL215	1560/hr	-	204.USG/hr	c.
Pawnee	400/hr	100/hr*	(1)	a.
HH3	500/hr	0.	(1)	d.
206B	600/hr	150/hr	(1)	e.
LWB	4000/day	-	(1)	a.
MWB	2000/day	-	(1)	a.
SWB	900/day*	-	(1)	

(1) Cost included in Operating Cost.

3.3 Results

The results of the calculation are shown in Figures 4 through 11.

Application Rate (Figures 4-7): The application rate in liters of dispersant per day is shown as a function of distance D from base to slick pattern in Figure 4 (pattern length = 0.6 km) and in Figure 5 (pattern length = 4.0 km). In both figures it can be seen that the vehicles fall roughly into three classes: large (fixed-wing) aircraft, small aircraft, workboats. The application rates differ between large and small aircraft by a factor of about 5.0; between small aircraft and boats by a factor of about 10.0. Further, it can be seen that the three classes have different ranges (i.e., the base-to-slick distance at which the application rate drops to one-half of its maximum value varies substantially). This distance, which may be termed the "half-range" is shown in Table 5. The large aircraft have half-ranges of 200-300 km, the small aircraft have half-ranges of 30-50 km, and the boats have half-distances of 20-30 km.

An important parameter in performance is L_p, pattern size; i.e., mean length of pass over the pattern. Roughly, this parameter corresponds to spill size; larger spills cover a larger area and usually have larger dimension, L_p. Figure 6 shows that, generally, the larger the mean pattern dimension L_p, the more effective the performance of the vehicle. (The one exception, the Pawnee, is due to its limited dispersant capacity relative to other fixed-wing aircraft operating in Pattern #1). In general, it is seen that the large aircraft and the HH3 operate more effectively for mean pass lengths above the 1.5 - 2.0 km range, while the other vehicles operate best with L_p above 0.2 - 0.5 km. Table 6 shows for each vehicle the minimum mean pass length for which it can achieve at least

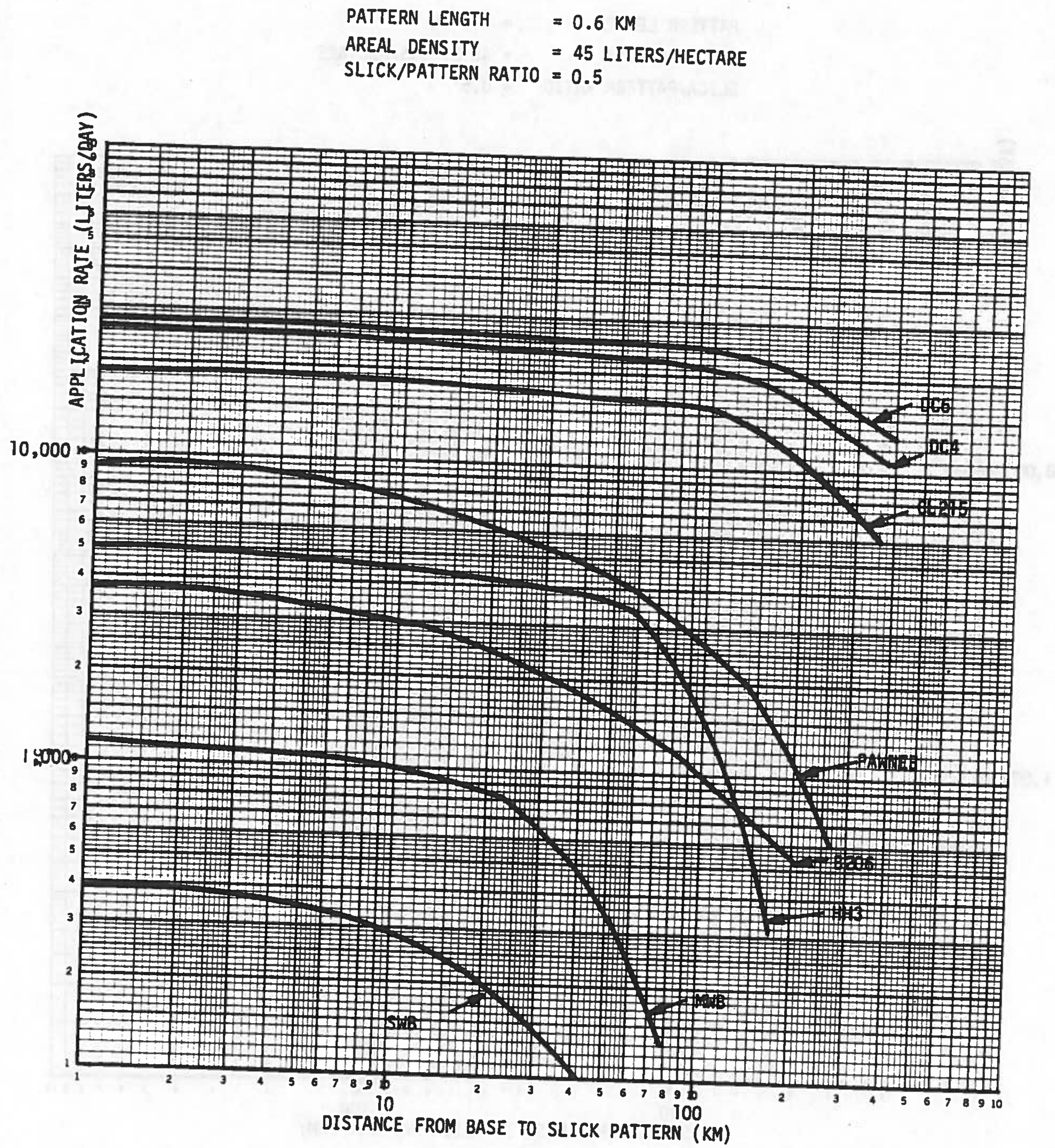

FIGURE 4. APPLICATION RATE VS DISTANCE TO SLICK FOR PATTERN LENGTH = 0.6 KM

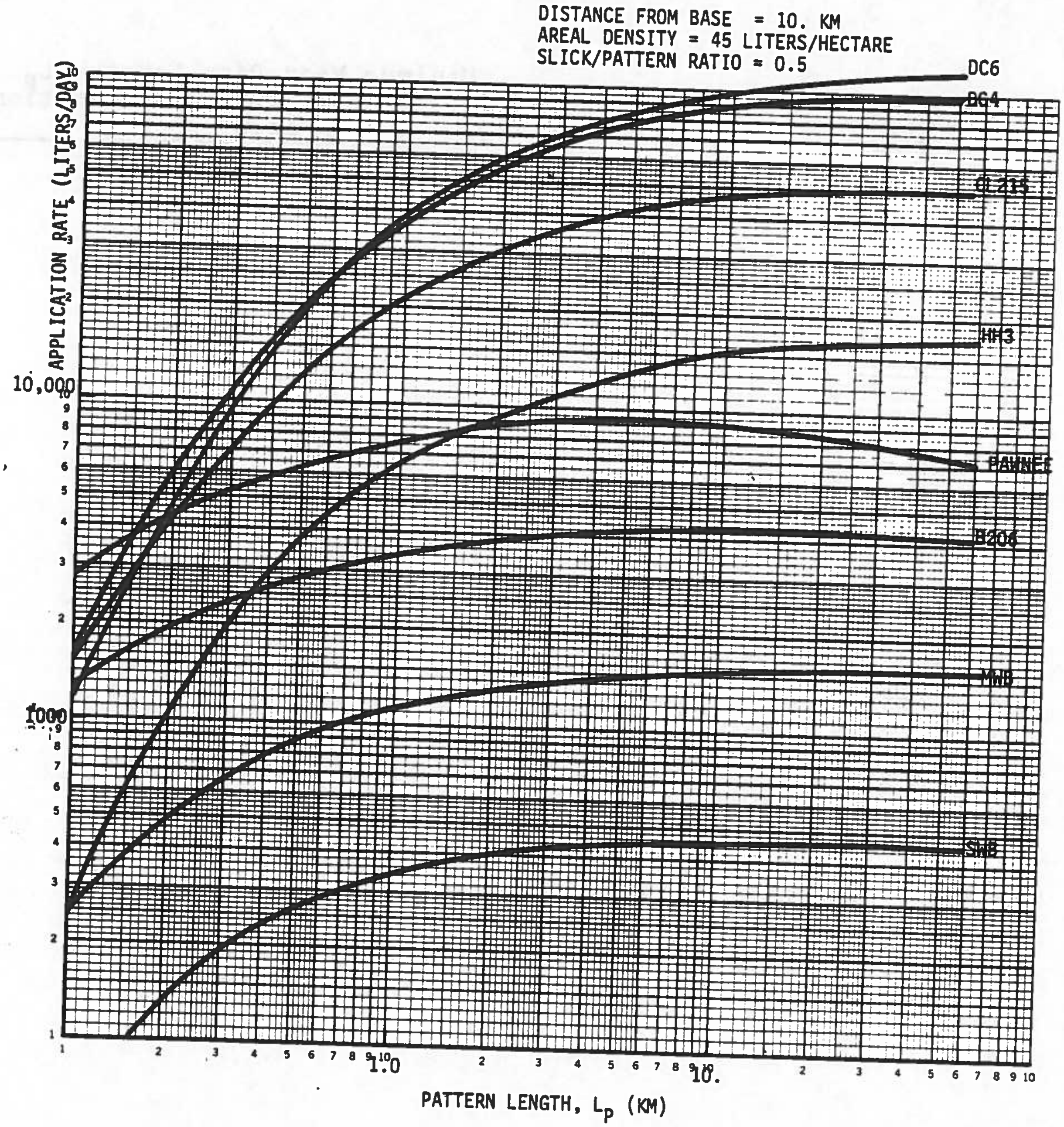

FIGURE 6. APPLICATION RATE VS DISTANCE TO SLICK FOR PATTERN LENGTH = 10. KM

one half of its full application rate. It is doubtful if any vehicle can operate effectively for slick pass lengths under 0.2 km under the speed assumptions made in the calculation. The speed assumptions can be lifted for the workboats and the two helicopters, but not for the fixed wing aircraft.

The final parameter varied in the calculation of application rate is areal density (Figure 7). Application rate increases, in general, with areal density of dispersant, because less time is required to apply a given amount of dispersant. The increase in daily application, however, is less than the increase in dosage, i.e., doubling the dosage does not double the total amount applied in a day. The reason for this is that the higher dosage rates deplete the vehicle's dispersant supply more rapidly and a greater fraction of the day must be spent in returning to the operations base for refilling dispersant.

The areal density of dispersant is usually selected arbitrarily if the effectiveness ratio is not known (the usual situation). It has been found that 45-90 liters/hectare (5-10 gallons/acre) is a convenient nominal dosage. The application is repeated if the first application does not result in good dispersion of the slick. This procedure is not as inefficient as one might estimate on a naive basis, as the following example shows:

Example: Suppose a slick of 600,000 liters of oil is to be dispersed with a product having a 1:20 effectiveness ratio under the given conditions. Therefore, about 30,000 liters of the product must be applied. Assume the vehicle chosen is a single Piper Pawnee. Then, from Figure 7, it can be seen that an areal density of 40 liters/hectare would result in 9,000 liters being applied per day, or 3.33 days to complete the operation. On the other hand, an areal density of 80 liters/day would result in 11,200 liters/day, or 2.68 days to completion. Thus, doubling the dosage has resulted in about a 20% reduction in the total operating time. This must be weighed against the increased risks of over-dosage presented by the higher dosage rate.

<u>Normalized Cost</u> (Figures 8-11): The cost of application in dollars (1979) per liter as a function of distance from base to slick pattern are shown in Figure 8 for a mean pass length of 0.6 km and in Figure 9 for a mean pass length of 4.0 km. The variation with pass length is shown in Figure 10, and with areal density in Figure 11.

The results seen in Figures 8 and 9 are as follows: for relatively short pattern lengths (L_p = 0.6 km) the DC-6 and DC-4 are the most economic vehicles over 10 km from the operations base, and only slightly less economic than the Pawnee less than 10 km from the base. Operating costs are well under $1.00 per liter for these vehicles. For longer pattern lengths (about 4.0 km, Figure 9) the DC-6 and DC-4 are even more attractive (about $0.20 per liter) than the Pawnee at short distances. Table 7 shows the cost per liter at 0 km distance and the distance at which the cost doubles for each vehicle. The DC-6 and DC-4 have low cost/liter and large ranges, regardless of mean pass length. At the other extreme the B206 and the workboats have high cost/liter and restricted range, regardless of pass length. The Pawnee has low cost but restricted range, regardless of pass length. The CL215 and HH3 are low cost only for the larger pass length, the range of the HH3 being much less than that of the CL215.

The variation of cost/liter with pass length is shown in Figure 10. The workboats and B206 are more expensive than the other vehicles for pattern lengths greater than about 0.3 km (about 1000 feet) but below about 0.5 km the Pawnee is distinctly less expensive than all the other vehicles.

Figure 11 shows cost/liter as a function of the dispersant areal density (liters/hectare). It can be

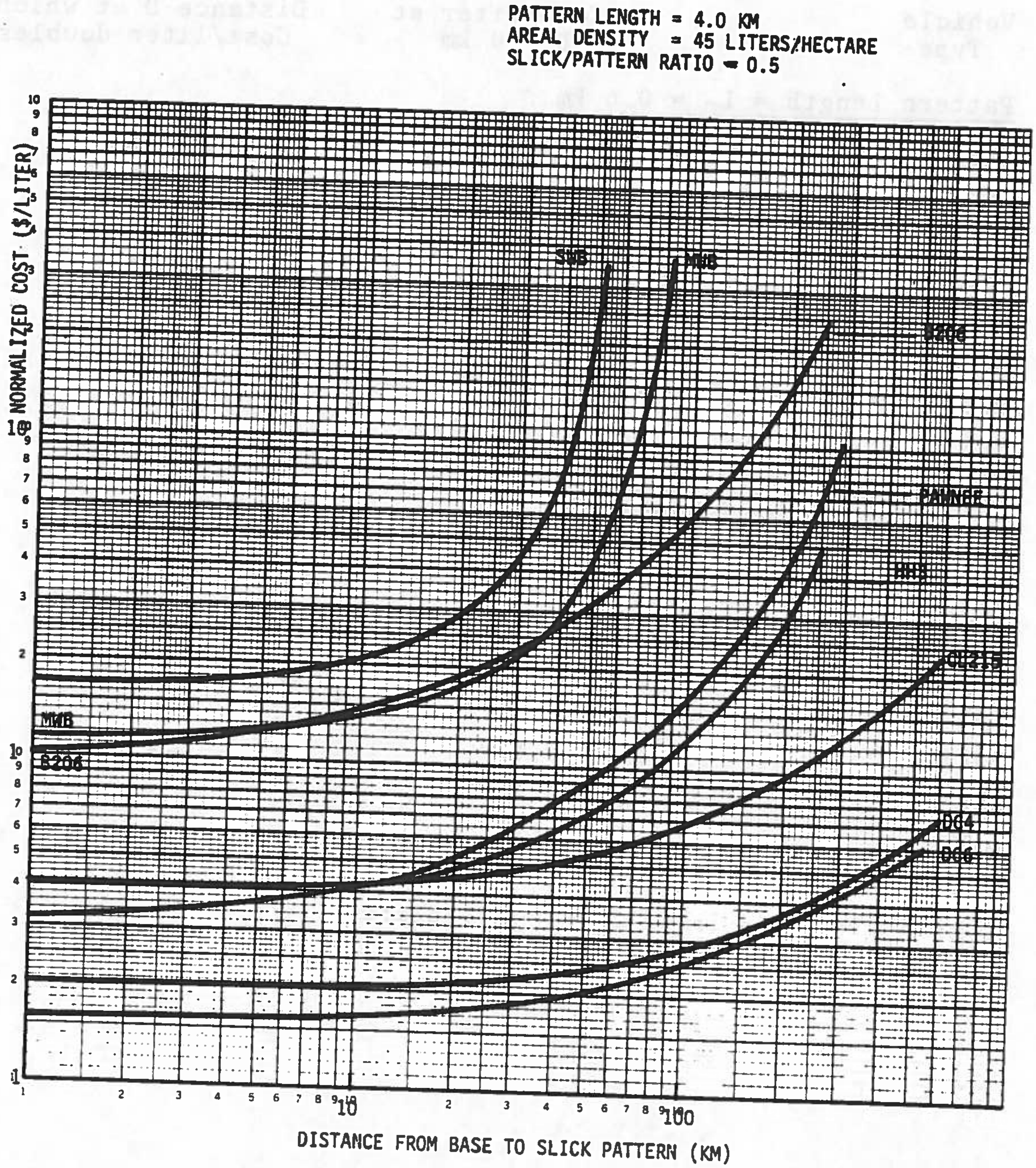

FIGURE 9. NORMALIZED COST VS DISTANCE TO SLICK FOR PATTERN LENGTH = 4.0 KM

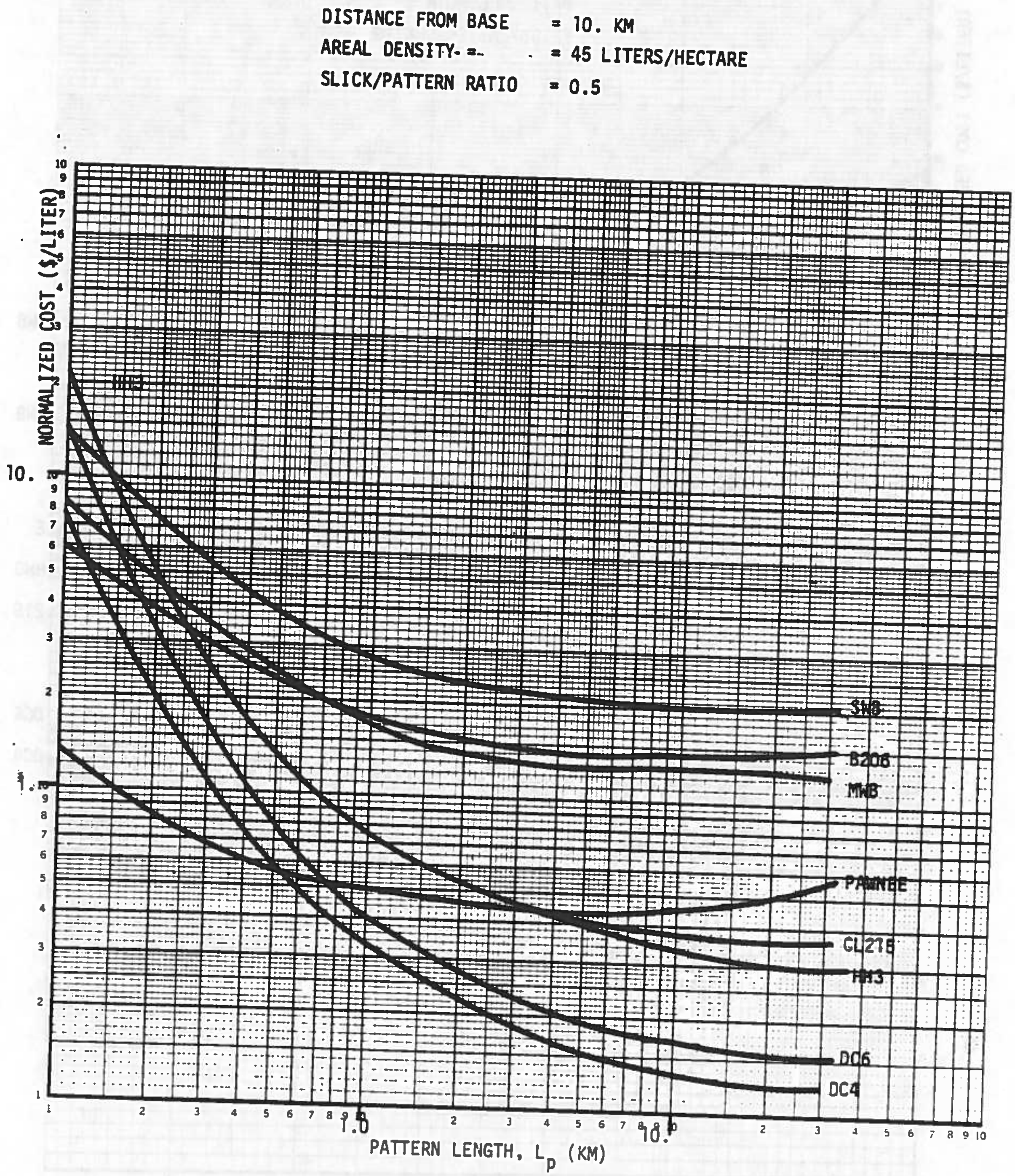

FIGURE 10. NORMALIZED COST VS DISTANCE TO SLICK FOR PATTERN LENGTH = 10. KM

seen that doubling the dosage does not cut the cost in half, for the same reason that it does not double the application rate in Figure 7.

Summary of Results

Application Rate: Large Aircraft (DC-6, DC-4, CL215) can apply about 20,000-80,000 liters per day of dispersant with ranges of 200-300 km. Small aircraft (Pawnee, HH3, B206) apply about 3,000-15,000 liters per day at ranges of 30-50 km. Workboats apply 300-2,000 liters per day up to 20-30 km. The DC-6, DC-4, CL215 and HH3 require mean pattern pass lengths of 1.6 km or more for effective application rates, while the Pawnee, B206, and workboats require 0.20 km or more. The DC-6, DC-4 and CL215, however, are still more effective than all other vehicles at pass lengths greater than 0.2 km, and more effective than all but the Pawnee at pass lengths greater than 0.1 km. Finally, doubling the dosage (liters per hectare) results in substantially less than twice the application rate (liters per day).

Cost: The DC-6 and DC-4 have the lowest application cost per liter ($.15-$.65) regardless of pass length, at ranges of 180 km or more. The Pawnee application cost is about $.30-.40 per liter with ranges of 30-40 km. At the other extreme, the B206 and workboats cost from $1.00 per liter to $2.36 per liter with ranges from 20 to 60 km. The application costs for the HH3 and CL215 depend strongly upon the mean pass length. The costs of ferrying, retainer fees, training, spotter aircraft, and of the dispersant itself are not included above.

Operators Association, while 40% is held directly by the UK Department of Transport and Ministry of Defense. (Reference 7)

1. FREQUENCY, SIZE AND LOCATION OF OIL SPILLS

In the period 1974-1977 the United States waters experienced about 20 spills per year of 50,000 USG or more. Approximately the same rate has been sustained in 1978 and 1979. The rate for spills of 1,000 gallons or more is approximately 630 per year, and oil spills of all sizes commonly exceed 10,000 per year in United States waters. Studies have shown that there are no significant differences in spill rates among major coastal areas. (Reference 8)

The largest size spill to have occurred within U.S. territorial waters is 10 million USG (Burmah Agate, Galveston, Texas, 1 November, 1979), but spills in the 50-100 million gallon range are possible off U.S. coasts where lightering of large crude carriers takes place. In general, however, the data on spills are inadequate to provide spill size distributions for separate coastal areas. As a result of these circumstances there is presently available only a single empirical distribution for spill size, and a single spill rate (i.e., spills per million tons of oil movement) for all United States coastal waters. Nevertheless, it is still possible to derive different levels of dispersant stock required in each of several coastal regions. This is possible because the different tonnages of oil movement in different regions result in unequal numbers of spills per year, on the average, in those regions. Areas with more spills (per year, not per ton movement) should be alloted larger stockpiles of dispersant because, having more spills in toto, they are more likely to experience one or more large spills.

In order to formulate mathematically the above reasoning it is necessary to make some assumptions. The first is that the U.S. waters have been divided into spill response areas, each served by a single stockpile of dispersants. It is assumed that the only dispersant available for a spill is that in the associated area stockpile, which is replenished after a spill cleanup is completed and before the next spill occurs in that area. Also, it is assumed which is to be maximized by choice of the stockpiles r_i, i = 1, 2, 3, ..., N, subject to the constraints:

$$\sum_{i=1}^{N} r_i \leq K, \text{ and}$$

$$r_i \geq 0, \; i=1, 2, 3, \ldots, N.$$

where K is the total national oil dispersal capability, in tons of oil. Maximizing $\overline{R}$ is equivalent to minimizing the amount of undispersed oil. It will be noted that in this formulation dispersant levels are measured by equivalent tons of oil that they can disperse.

Solutions to the above problem can be found by computer or graphically. (Reference 8, Volume II, Appendix K) To solve the problem it is necessary to have cumulative distribution F(x) of spill size x. It is necessary also to have values $\overline{n}_i$ for the expected number of spills per year in the area covered by each stockpile, i. A graphical solution was worked out as outlined in Reference 8, Volume II, Appendix K using the cumulative distribution of spill sizes for spills over 50,000 gallons (189,250 liters) in the U.S. in 1974-77, taken from Reference 8, Vol. I, p. 21. This cumulative distribution is shown in Figure 12. The values of $\overline{n}_i$ employed were derived from the same spill data as were employed to produce this figure, with adjustment for the 1980-1990 time frame. The values of $\overline{n}_i$ are shown in Table 8. The eleven stockpile locations in Table 8 are the bases that serve eleven spill response regions covering the U.S. coastal waters within 12 hours in 97% of historic spill cases.

The dispersant stockpiles that result from the calculation are given in Table 9.A and the percent of oil treated is given in Table 9.B.

The realism of the above formulation is limited primarily by the assumption that a spill is treated only from the stockpile in

TABLE 8. ANNUAL SPILLS IN U.S. COASTAL REGIONS SERVED BY ELEVEN SPILL RESPONSE BASES

	i, Stockpile Location	n_i, Expected Number of Spills/yr
1.	Elizabeth City, NC	0.84
2.	Bay St. Louis, MS	3.97
3.	San Francisco, CA	1.84
4.	New York, NY	2.19
5.	Philadelphia, PA	2.37
6.	Boston, MA	1.43
7.	Miami, FL	0.63
8.	Galveston, TX	3.08
9.	Los Angeles, CA	1.61
10.	Seattle, WA	0.52
11.	Kodiak, AK	3.60
		22.08

Notes: (1) Spills served by closest stockpile
(2) Based on national spill rate for spills of 50,000 US gallons or more

TABLE 9.B AVERAGE PERCENT OF SPILLED OIL THAT CAN BE TREATED WITH DISPERSANTS FROM ELEVEN STOCKPILES

	5.4MT	3.8MT	2.9MT	2.4 MT	1.9 MT
Elizabeth City, NC.	92%	62%	60%	53%	52%
Bay St. Louis, MS	100	97	96	94	90
San Francisco, CA	98	92	85	76	68
New York, NY	99	94	89	82	73
Philadelphia, PA	99	95	91	84	77
Boston, MA	98	88	77	67	59
Miami, FL	85	61	51	50	46
Galveston, TX	100	96	95	90	85
Los Angeles, CA	98	89	81	71	63
Seattle, WA	81	61	44	46	34
Kodiak, AK	100	97	95	92	88
US Weighted Average	98%	92%	87%	78%	76%

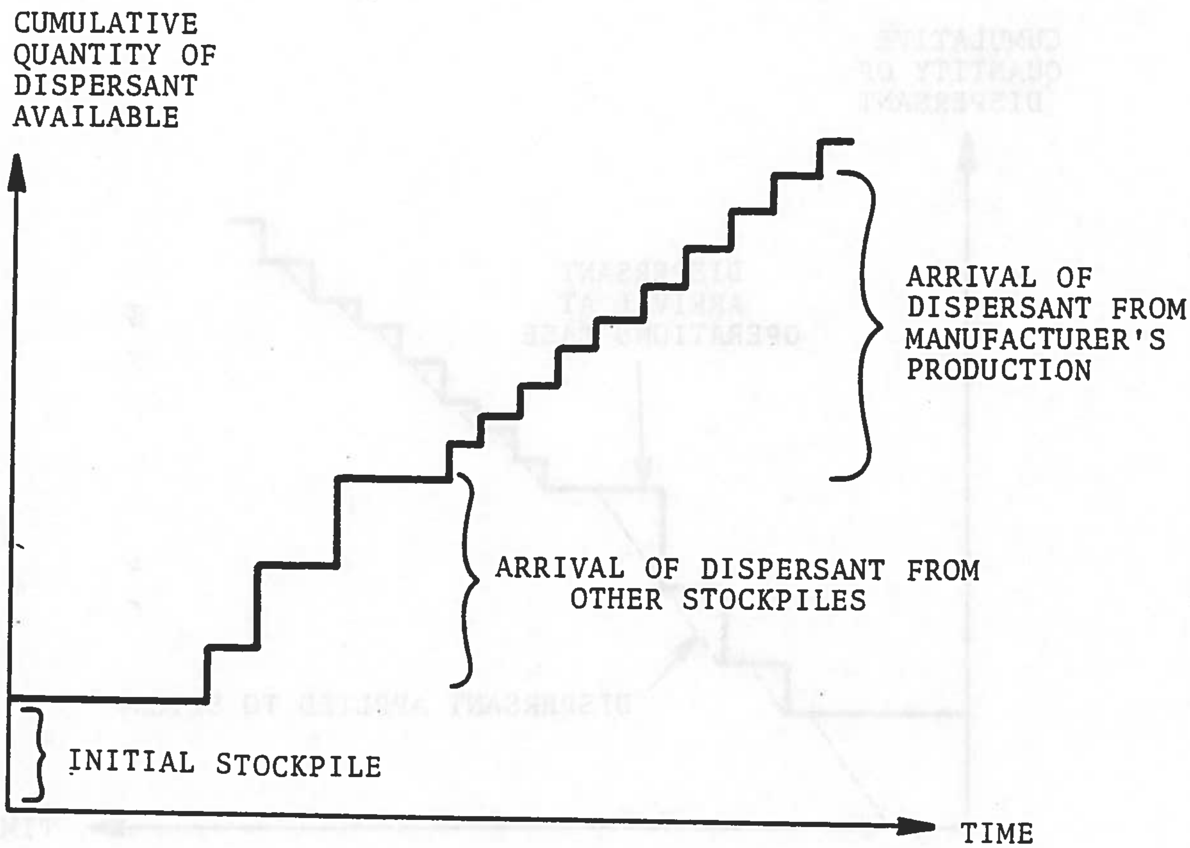

FIGURE 13. HYPOTHETICAL PLOT OF DISPERSANT AVAILABILITY AS A FUNCTION OF TIME

2. FRACTION OF SPILLED OIL AMENABLE TO DISPERSANTS

The amount of dispersant required to treat a spill depends not only on the ratio of dispersant to oil (effectiveness ratio) but also on what fraction of the spilled oil needs to be treated. Unlike mechanical cleanup methods, dispersants can have undesirable ecological effects so that they are employed only if the following processes are inadequate:

1. mechanical cleanup
2. evaporation and dissolution
3. transport to sea by wind and currents.

Further, dispersants are likely to be used only when some ecologically sensitive shoreline, or natural amenity, is threatened by the oil.

<u>Open Water</u>

Historically, mechanical cleanup of spills in open water has recovered only a small fraction of the spilled oil. Mechanical cleanup also cannot be expected to be effective in rivers, channels and other areas of high currents. All tolled, mechanical cleanup cannot be expected to reduce spill size by more than 5%-10% on the average, as a rough estimate.

Evaporation commonly removes a substantial fraction of spilled oil. It can be expected to remove 80%-90% of gasoline, kerosene and light distillate spills in 12 hours or less, depending on water temperature and oil composition. It can remove from 20% to 40% of crudes within one day; but the evaporation loss from residual oils is usually less than 10%. If oil shipments by water are 40% crude, 30% light distillates, and 30% residual oils, then average evaporative losses might be estimated as $\bar{E}$,

$$\bar{E} = .4 \times 30\% + .3 \times 80\% + .3 \times 10\%$$

$$= 40\%$$

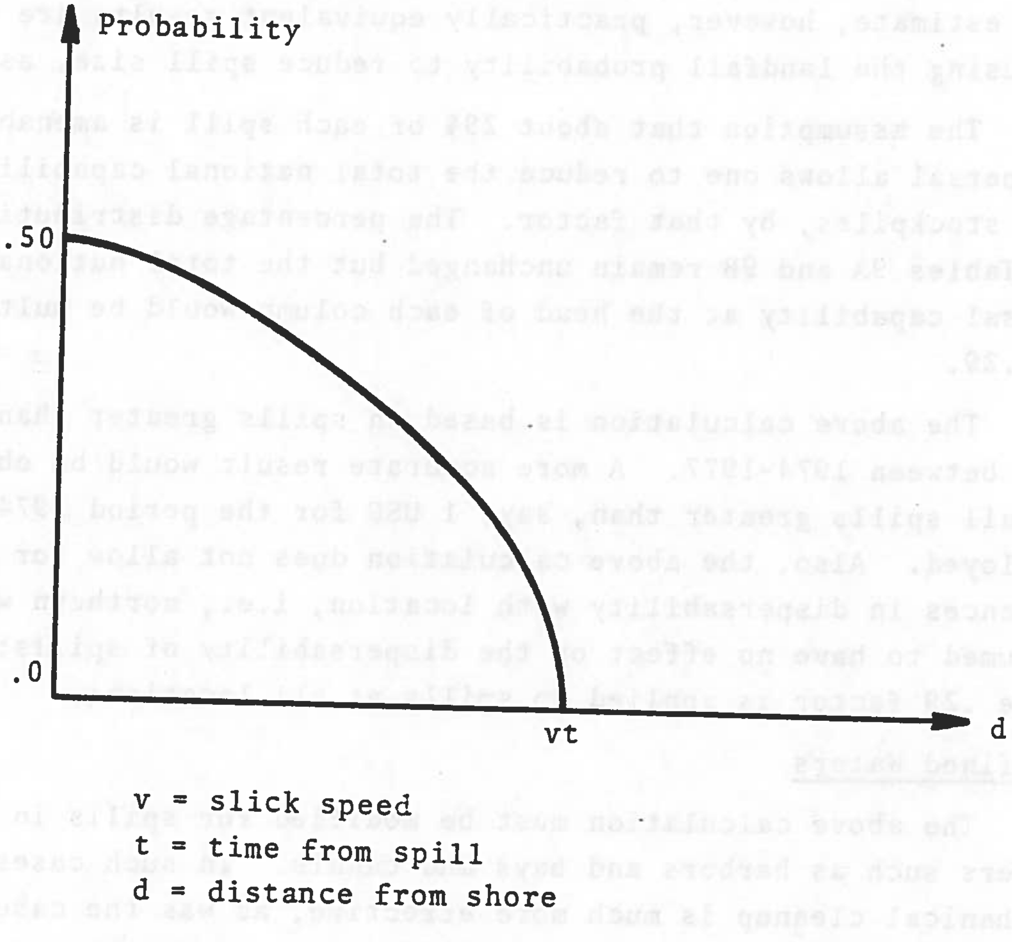

FIGURE 15. PROBABILITY OF A SLICK IMPACTING A SHORELINE IN TIME t.

3. NON-USCG STOCKPILES AND PRODUCTION

An inventory of U.S. stockpiles of dispersants is given in Volume I. The results are summarized in Table 10. These supplies are of dispersants having data accepted by the U.S. Environmental Protection Agency, held by companies and cooperatives in the U.S., and available for U.S. Coast Guard use as of February 1980. (Some cooperatives and companies hold supplies committed to specific users, outside of U.S. waters, which supplies are not included in Table 10.) The total stockpiles available for U.S. use are seen in the table to be about 0.44 million liters of all types. The stockpiles in the United Kingdom are about eight times these levels, being about 1.65 million liters of ordinary and about 1.79 million liters of concentrate dispersant.

In addition to stockpiles, one must consider production capability. A short period of time (in the order of a few days) is usually required to start up production, after which a daily production can be sustained for long periods. Table 11 shows production lead times and rates for dispersant production in the same regions given in Table 10. Lead times are given approximately in parentheses, in days. Delivery times must be added to these lead times, to be discussed next.

4. DISPERSANT TRANSPORTATION

Several options for transporting dispersants from stockpiles to the operations base are available, depending on distance, quantity and packaging. Under the Massive Spill Logistics Contingency Plan prepared for the Coast Guard, it would be the responsibility of the Logistics Coordinator to expedite the movement of non-USCG supplies to a spill, if the supplier is unable to provide timely transportation. The stockpiles listed in Table 10 are in 55-USG drums except for about 13% of the hydrocarbon stockpile, which is in 25-liter pails, and part of the concentrate which is in 90- and 180-BBL tanks.

TABLE 11. AVERAGE DISPERSANT PRODUCTION AVAILABLE TO THE U.S. COAST GUARD IN FEBRUARY 1980 - LITERS/DAY

Region	Water-Based	Hydrocarbon	Concentrate
Mid-Atlantic (NY to NC)	65,600.(1)	11,000.(1)	-
South East (SC to AL)	99,000.(7)	-	-
Western Gulf (MS to TX)	78,000.(1) 93,700.(7)	52,000.(7)	52,000.(1) 125,000.(7)
West Coast (CA to WA)	52,000.(1)	-	-
Total U.S., liters per day	195,600.(1) 192,700.(7)	11,000.(1) 52,000.(7)	52,000.(1) 125,000.(7)
Total U.S., gallons per day	51,700.(1) 50,900.(7)	2,900.(1) 13,700.(7)	13,700.(1) 33,000.(7)
Total U.S., tons per day	172.(1) 167.(7)	10.(1) 48.(7)	10.(1) 110.(7)

NOTES: (a) Numbers in parentheses indicate approximate start-up time, days.

(b) No production in Alaska or New England.

This method takes longer to load than 3. or 4. above but results in about a 50% increase in dispersant payload for the C141 and about a 33% increase for the C130H.

6. Commercial air freight can be obtained for about \$.04/per 100 lb/n. mi. but unless high fees are paid to reserve cargo aircraft for immediate use, delivery times of 1-5 days can be expected. Although these lead times are not suitable for the initial phases of a spill response they are often within the time frame of an extended spill cleanup, such as might occur from an offshore well blow-out.

10-, 15- and 25-liter Pails

A small part of the inventory listed in Table 10 is contained in 25-liter pails. These packages are inefficient to move and should be discounted for other than local use.

Storage Tanks

Inventories held in portable tanks up to 8' diameter are amenable to transportation by flat-bed trailer. Tanks of about 100 BBL (4200 USG) can be transported by conventional flat-bed semitrailer of 50,000 lbs capacity. Larger tanks cannot be easily transported except by transferral to a motor tank truck or rail tank truck. Motor tank trucks are readily available to hold and transport up to 9,000 USG, at purchase prices up to \$100,000. Rail tank cars are commonly available in 80,000 USG sizes but other sizes are also available. Storage tanks of the 90 BBL variety require a crane for loading and offloading on a semitrailer or vessel. Motor tank-trucks must be loaded and unloaded by pump; petroleum motor carriers commonly are outfitted with pumps for off-loading.

The availability of the above transport modes may be characterized in terms of hours required from the time the decision is made to use the mode to the time of arrival at the operations base. These times are estimated for 55-USG drums

TABLE 12. DISPERSANT DELIVERY TIMES BY VARIOUS MODES FROM STOCKPILE TO OPERATIONS BASE-55 USG DRUMS

1. USCG tractor semi-trailer carrying 55 USG drums:
   (a) drums preloaded: .25 + D/33.33 hours
   (b) drums in storehouse: 2.0 + D/33.33 hours

2. Rental tractor and semi-trailer, hauling 55 USG drums from USCG or other stockpile:
   (a) minimum: 4.0 + D/33.33
   (b) average: 6.0 + D/33.33

3. USCG tractor semi-trailer carrying 55 USG drums to local airport; C130 flight of semi-trailer and load to destination airport; tractor semi-trailer over the road to operations base:
   (a) preloaded: 3.25 + D/300.
   (b) not preloaded: 5.00 + D/300.

4. Same as 3. except C141 aircraft is employed instead of USCG C130:
   (a) preloaded: 8.0 + D/500.
   (b) not preloaded: 8.0 + D/500.

5. 55 USG drums on pallets loaded onto aircraft at USCG air base by forklift, operating from stockpile at airport; loaded onto semi-trailer or truck at destination airport, then hauled to operations base:
   (a) using USCG C130: 2.0 + D/300.
   (b) using DOD C141: 8.0 + D/500.

6. Same as 5. except destination airport is also the operations base:
   (a) using USCG C130: 1.0 + D/300.
   (b) using DOD C141: 7.0 + D/500.

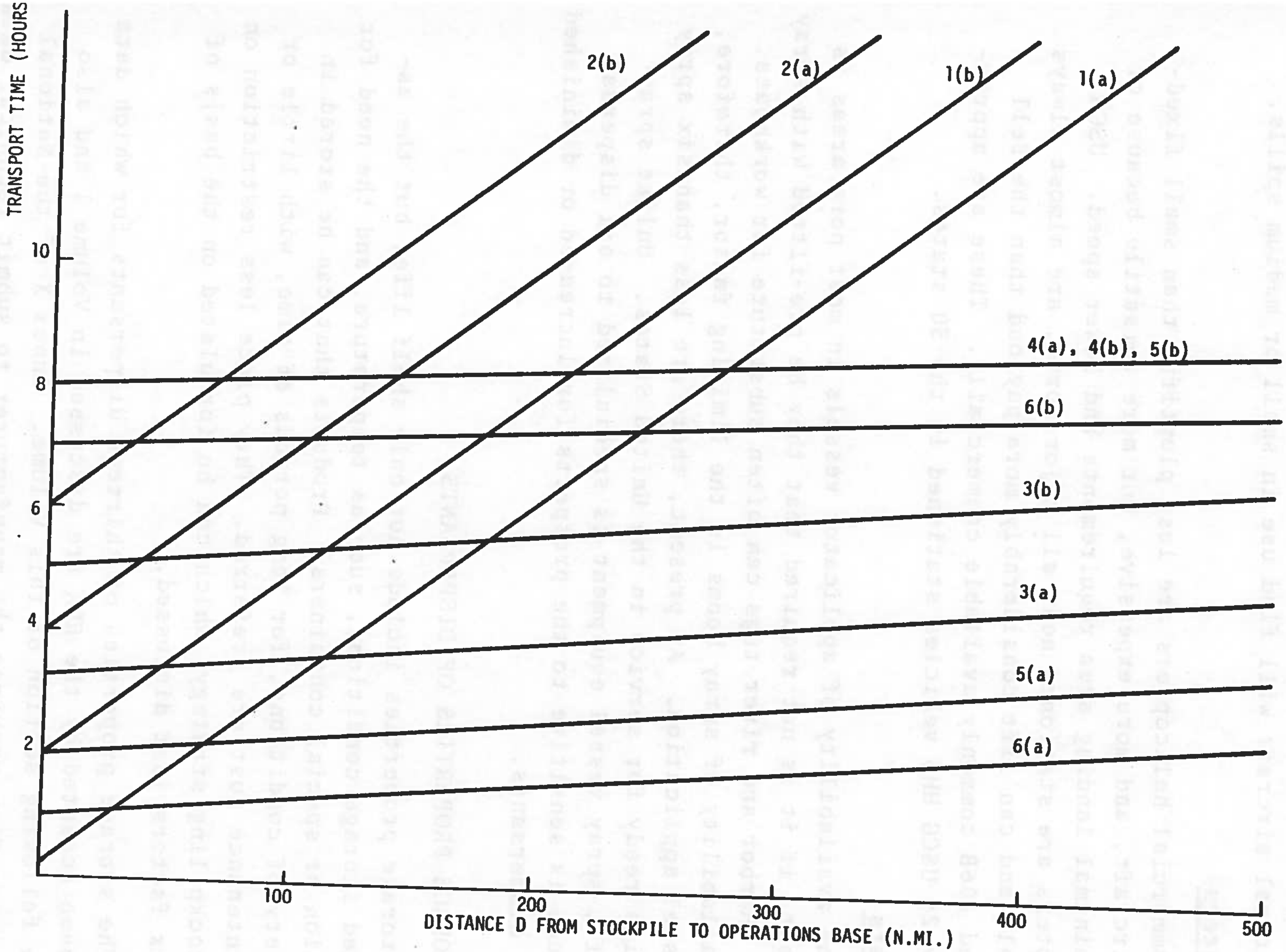

FIGURE 16. DISPERSANT DELIVERY TIMES BY VARIOUS MODES FROM STOCKPILE TO OPERATIONS BASE - 55 USG DRUMS (FROM TABLE 21.)

regarding the "maximum and minimum storage temperatures to include optimum ranges as well as temperatures that will cause phase separation, chemical changes or otherwise damage effectiveness of the chemical agent." Generally, the data submitted do not state the basis on which the minimum or maximum storage temperatures are determined, and they must be modified in some cases by phase separation and/or freezing point temperatures which are not always given under Annex X. Further, shelf life in some cases is stated as "unlimited". Finally, if the actual storage temperatures are below the minimum pumpability temperature of the dispersant for part of the year, the storage area may have to be heated partly in order to maintain the product fluid enough to be used on short notice.

The implications of the above uncertainties is that any stockpiles may be expensive to maintain because of the need for heating and/or maintenance (such as periodic agitation). Also, if, even under "optimum" conditions the dispersant has a short shelf life, their stockpiles will have to be replaced periodically at additional cost. Therefore it may be concluded that improvement of storage characteristic data is important to the stockpiling question.

A fuller discussion of the storage and handling problems presented by dispersants is given in the following section.

TABLE 13. SUMMARY OF STORAGE AND HANDLING PROPERTIES OF THREE DISPERSANT TYPES

	W								H			C	
Product #	1	2	3	4	5	6	7	8	10	11	13	9	12
Pour Point													
H: >20°F			✓		✓	✓	✓	✓					
M: 0°-20°F	✓	✓		✓									
L: < 0°F									✓	✓	✓	✓	✓
Flash Point													
H: >212°F	✓	✓	✓		✓	✓	✓	✓					
M: 150°-212°F									✓	✓	✓	✓	
L: <150°F				✓									✓
Viscosity @100°F													
H: >100 SSU	✓	✓		✓	✓	✓	✓	✓				✓	
L: <100 SSU			✓						✓	✓	✓		✓
Min Storage Temp													
H: >20°F					✓		✓					✓	✓
M: 0°-20°F	✓			✓		✓				✓			
L: < 0°F		✓	✓						✓		✓	*	
Shelf Life													
H: >60 mos		✓		✓		✓		✓	✓	✓	✓	✓	✓
M: 36-60 mos					✓		✓						
L: <36 mos	✓		✓										
Combustible				✓					✓	?	✓	✓	?
Irritant				✓					✓	?		✓	?

Notes: W = waterbased, H = hydrocarbon-based, C = concentrate
H,M,L = high, medium, low

*Manufacturer's data sheet.

The implications of the above for dispersant selection are that the Annex X data are not adequate to determine the conditions under which a heated storage area is required for any given product.

As pointed out in the preceding section, there are substantial implications for the question of stockpiling.

(2) Shelf Life: The thirteen subject dispersants show shelf lives from 18 months to "unlimited".

The EPA-accepted dispersants have shelf lives stated as follows (in ascending order)

1 product	:	18 months
1 product	:	greater than 24 months
1 product	:	24 to 60 months
1 product	:	greater than 36 months
3 products	:	greater than 60 months
3 products	:	indefinite
3 products	:	unlimited

The economic value of a long shelf life depends on restock policy, production lead time and production level. Although Warren Spring Laboratory specified 5 years minimum shelf life, the value of that specification needs to be assessed for U.S. stockpiles and production capabilities.

The shelf-life requirement suitable for a USCG-stocked dispersant must be determined in the overall context of a dispersant deployment strategy.

3. APPLICATION CHARACTERISTICS

The major characteristics bearing on dispersant application are described below by ten parameters. Information for the subject dispersants relative to four of the parameters (Water Salinity, Equipment Type, Agitation, Mixing) is summarized in Table 14.

(1) Oil Type, Weathering and Emulsification: There is evidence that dispersants vary in effectiveness on different types of oil. Some results are available from the Canadian Environmental Protection Service, covering 4 of the subject dispersants and four types of oil. (Reference 10.) The US EPA effectiveness tests cover the 13 subject dispersants for No. 2 and No. 6 oils. These results show a great deal of variability among dispersants and from oil to oil. Although the EPA data show water based dispersants to be significantly less effective than the hydrocarbon or concentrate dispersants after 2 hours on No. 2 oil they show no significant difference on No. 6 oil. (Volume I, Appendix A)

(2) Slick Thickness: Thicker oil slicks impede the penetration of dispersant and retard dispersion. Differences among dispersants in slick penetration, however, are largely unknown.

(3) Water Temperature: Two of the 13 subject dispersants showed about a 23% drop in effectiveness in 40°F water compared to 62°F water, based on Canadian Coast Guard tests on a crude oil, Reference 11. Similar results have been reported by the Canadian EPS, Reference 10. The results seem to suggest that the drop in effectiveness is similar for most dispersants, but full comparative data do not yet exist.

(4) Water Salinity: About 30% of US oil movement is in fresh water (e.g., the upper Delaware River). (See Volume I, Table 9.) Eight of the 13 products are recommended by their manufacturers for use on fresh water spills; four bear no explicit recommendation, and one product is recommended only for salt or brackish water spills. See Table 14. Actual effectiveness comparisons for salt and fresh water, however, are available for only four of the 13 dispersants.

(5) Wave Conditions: Many dispersant manufacturers imply in their literature that wave action alone can produce effective dispersion in some cases. An interpretation of their literature can be taken (Table 14) showing that six of the 13 producers consider agitation

TABLE 15. APPLICATION METHODS RECOMMENDED BY DISPERSANT MANUFACTURERS

Disp. Product #/Type	Hand-carried Spray Tanks -land	-boat	Disp. Pump Syst.	Pump-Eductor Syst.	Dual Pump Syst.	Aerial Spray Syst.	Note
1/W	- no specific application methods recommended -						
2/W	X	X	X	X		X	(1)
3/W	X			X	X	X	
4/W	X	X	X	X	X	X	
5/W	X	X	X				
6/W				X		X	(2)
7/W			X	X			
8/W				X			
9/C		X	X	X	X	X	(3)
10/H	X	X				X	
11/H	X	X	X				
12/C					X		(3)
13/H	X	X	X	X	X		

(1) In calm waters additional agitation may be needed for aerial application.

(2) Dilution with 20 parts fresh or salt water recommended for aerial application.

(3) Has been applied by air in tests or actual spill or both.

TABLE 16. MANUFACTURER'S MIXING[1] RECOMMENDATIONS

Product/Type	Neat	Mixed, Type of Water	Mixing Ratios
1/W	Yes	Yes, Fresh or Salt	1:5 - 1:40
2/W	Yes	Yes, Fresh or Seawater	1:40 - 1:80
3/W	Yes	Yes, Fresh or Salt	1:10 - 1:40
4/W	Yes	Yes, Fresh or Seawater	1:5 +
5/W	Yes	No	
6/W	No	Yes, Fresh or Salt	1:20 - 1:500
7/W	Yes	Yes, Fresh or Salt	1:15 - 1:50
8/W	No	Yes, Fresh or Seawater	1:20 - 1:80
9/C	Yes	Yes, Seawater	1:10 - 1:20
10/H	Yes	No	
11/H	Yes	No	
12/C	Yes	Yes, Seawater	1:9
13/H	Yes	Yes, Fresh or Seawater	

(1)Mixing here means dilution at time of application

7. CONCLUSIONS

The conclusions are drawn from EPA Technical Product Bulletins, published reports, and manufacturer's literature for the thirteen dispersants for which the EPA has accepted data as of October 1979.

1. Although full hazard assessment data should be obtained for all products, it appears that all the dispersants but one have adequately high flash points for normal use.
2. Toxicity, causticity and reactivity information indicates that no handling problems can be expected from those sources, assuming normal precautions are observed. These precautions include, for some products, use of gloves, goggles and protective clothing.
3. Data are generally inadequate to determine minimum practical storage temperature. The most significant deficiencies occur in regard to viscosity, freezing points, and phase separation points.
4. Shelf life requirements need to be established in the context of inventory data, inventory strategy, and production capability.
5. There are no published data on effectiveness for most of the dispersants applied to crude oil. Canadian and UK sea tests on Kuwait and Tia Juana crude showed full dispersion at 1:20 to 1:8 ratios for two of the dispersants, with and without agitation.
6. EPA-accepted data for effectiveness on No. 2 oil show no significant correlation with data on No. 6 oil. They also show water-based dispersants to be significantly less effective than hydrocarbon-based on concentrates on No. 2 oil, but not on No. 6 oil. They do not cover variation of effectiveness with water temperature, slick thickness or agitation level.

OPERATIONAL STRATEGIES FOR DISPERSANT USE

The preceding sections of this report have analyzed the major operational factors in the use of oil spill dispersants by the U.S. Coast Guard. They are:

1. Choice of application technique
2. Stockpile locations and sizes
3. Choice of dispersants

These three factors are essential to any operational strategy for dispersant use. The purpose now is to formulate several possible operational strategies and to evaluate them in regard to total cost and response effectiveness. The first steps will be to summarize the conclusions that can be drawn from the preceding sections on the three key factors.

1. CHOICE OF APPLICATION VEHICLES

The DC6, DC4 and CL215 are far superior to the other vehicles in dispersant application rate for pass lengths above 0.2 km and for all distances from operations base to slick pattern. For pass lengths under 0.2 km, the Pawnee has a higher application rate up to about 12 km from base to spill. Practical considerations, however, make it impossible to employ fixed-wing aircraft close to piers or bridges, in narrow harbors, or along shorelines with prominent bluffs, irregular shape or large structures. In those conditions the HH3 or B206 are the obvious choices, from the point of view of application rate.

From the point of view of cost, the conclusion is similar: The DC6 and DC4 have the lowest cost per liter except for pass lengths less than 0.6 km and distances less than 10 km, where the Pawnee is superior, and except for operations close to obstructions such as bluffs or buildings or bridges where the helicopters are superior.

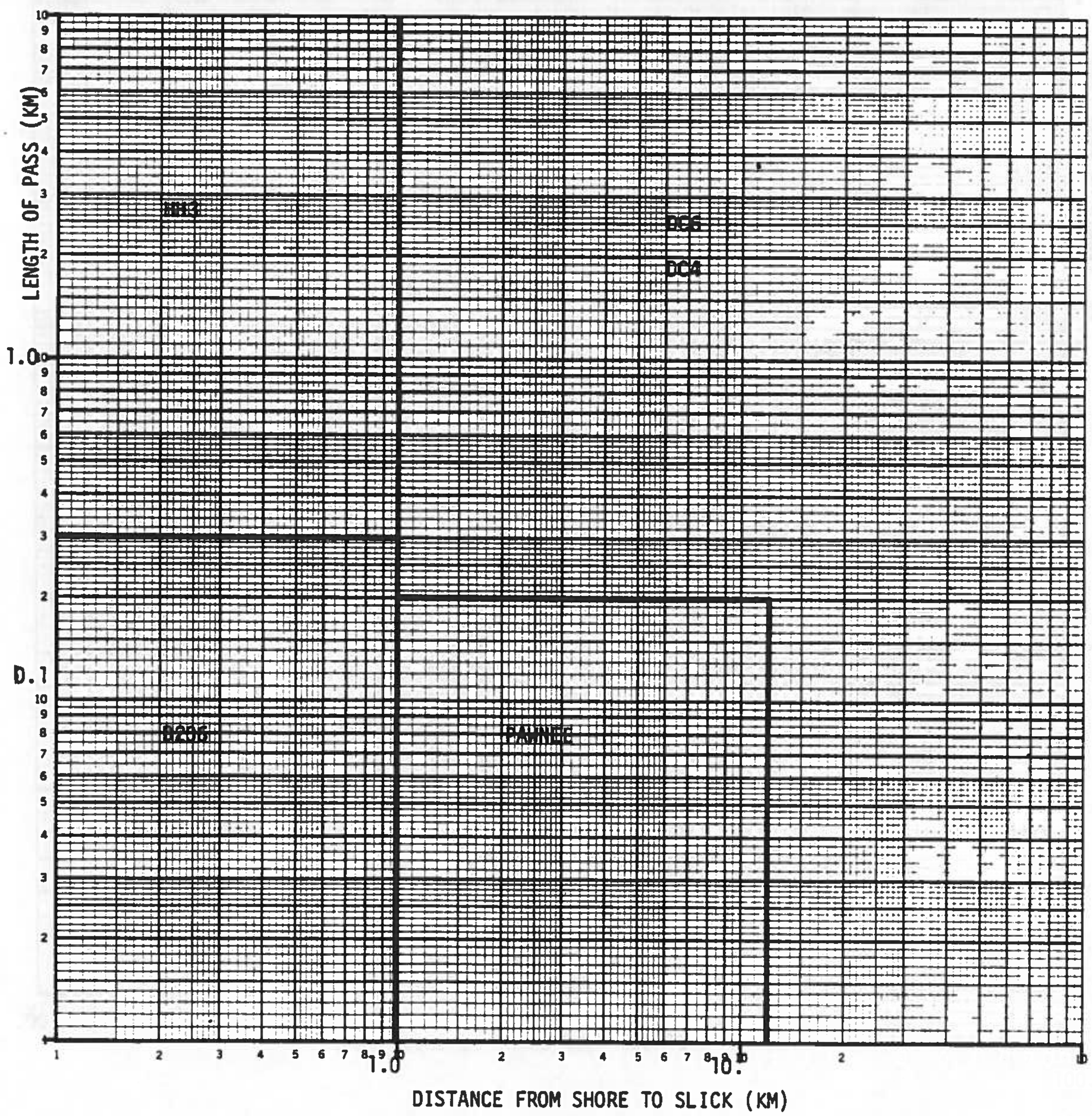

FIGURE 17. VEHICLES HAVING GREATEST APPLICATION RATES IN VARIOUS REGIMES

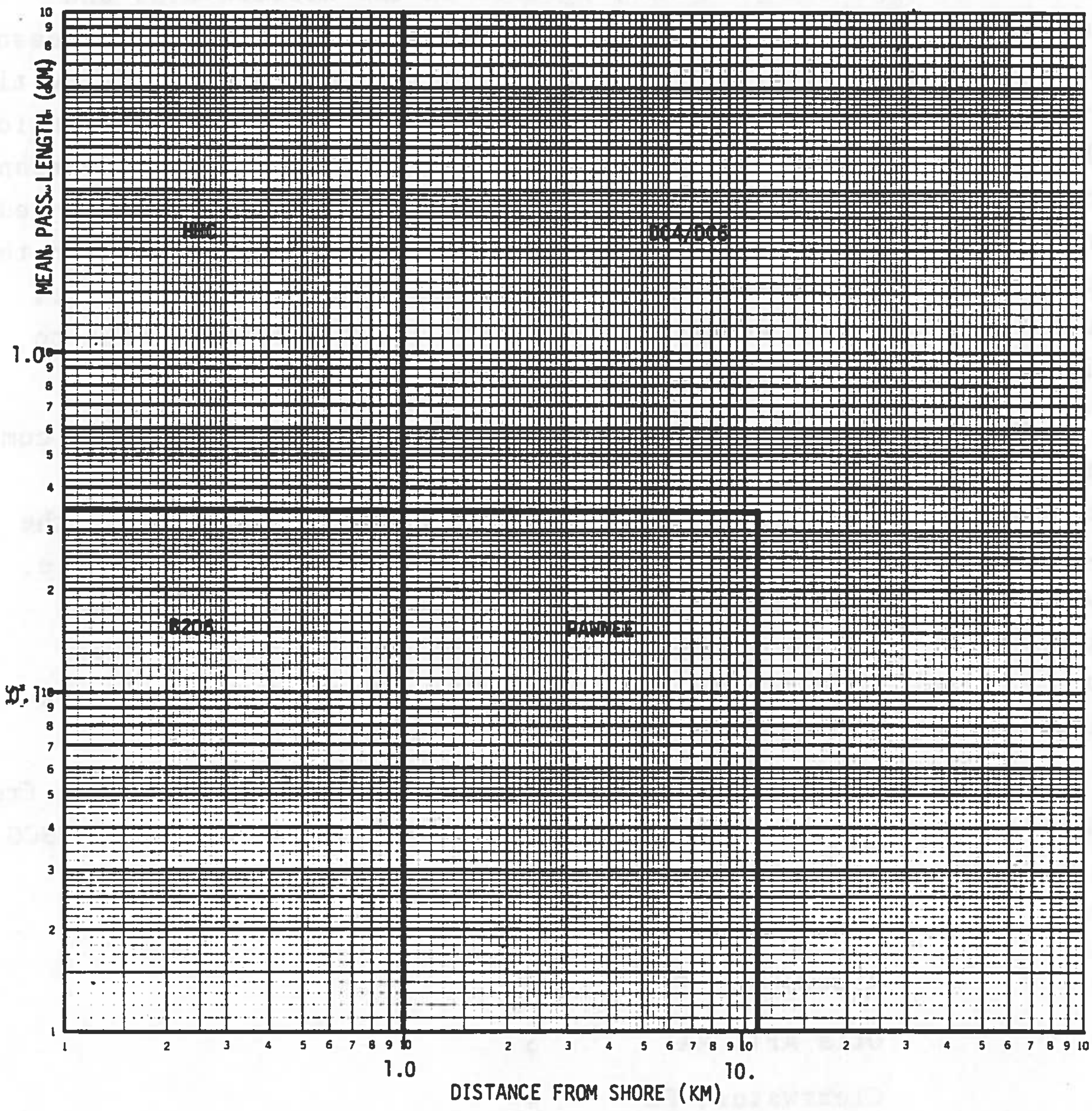

FIGURE 19. VEHICLE OF CHOICE FOR DIFFERENT OPERATING REGIMES

San Diego, CA	3
Sitka, AK	3
	29

When operated in a belly-slung (two way mission) mode, it has a maximum payload of about 2500 lbs over a range of 140 n. mi. The ferry range with external payload is about twice that distance. These ranges are shown in Figure 20. The dots represent oil ports with over 1,000,000 tons of crude or heavy oil movement per year. At 60 knots, the time to maximum range is 2.33 hours for the two-way mission and 4.67 hours for the ferry flight. If the load is carried internally, the ferry range (not shown in Figure 20) is about 400 n. mi. which is almost adequate to bring a New Orleans based vehicle to Corpus Christi or a San Diego based vehicle to San Francisco. This trip takes about 3 hours.

The bucket equipment for HH3 use is typically a 300 gallon bucket with a 32 foot boom. The boom folds, yielding an envelope of about 5' x 5' x 15', which can be stowed within the HH3. Total weights are about 350 lbs empty, and 2750 lbs full. Maximum pumping rate is 100 gallons per minute (380 liters per minute).

There are three possible dispersant missions for the HH3, depending on distance from the HH3 base to the spill.

(a) Direct Two-Way. The HH3 carries the externally mounted bucket/boom outfit to the spill site, applies the dispersant and returns to the base. This mission covers about 60% of all expected oil spills. (See Figure 20 and Table 8.) The solid circles in that figure, corresponding to the 140 n. mi. range of this mission, do not encompass the major oil movement areas in New York, New Jersey, upper Delaware Bay, Calcasieu-Lake Charles, any part of Texas, or San Francisco. Response time, however is less than 3 hours from request to application.

(b) Direct One-Way. The HH3 carries the externally mounted bucket/boom outfit to the spill, applies the dispersant and lands at a nearby base. Operations are then continued from the new base, close to the spill. Response time is less than 5 hours from request to application of dispersant, but maximum range is about 250 n. mi. (Dashed circles in Figure 20.) The second application is more rapid than the first, since the new base is closer to the spill, and the 5 hours required to respond may be used to bring more dispersant to the new base.

(c) One-Way Ferry. If the distance from the HH3 station to the spill is greater than 250 n. mi., but less than 540 n. mi., the mission may be accomplished by ferrying the spray equipment and dispersant internally from the HH3 station to an operations base near the spill. The HH3 is there refuelled, while the spray gear is removed, and a direct two-way externally mounted mission (as (a) above) is launched from the operations base. The total range is the sum of the ferry range and the direct two-way mission range. Total time is 6 hours or less.

Pawnee. The Piper Pawnee is typical of the small fixed-wing agricultural aircraft in the U.S. Although thousands are available, they are less available in industrialized seaports than inland. Availability times range from 1-2 hours to 1 day, depending on the spill location. The conditions regarding fuel, crew, nozzles, ferrying, and training are similar to those for the large fixed wing or B206.

2. LOCATIONS AND SIZES OF STOCKPILES

Present oil response equipment deployment is planned for eleven USCG bases. If these bases are also dispersant stockpile locations, the percentage of the total national dispersal capability that should be located at each base so as to maximize the amount of oil that can be treated directly from the closest base is given in Table 9A. These theoretical percent distributions must be modified by several practical considerations:

(a) Only a fraction of the spilled volume is amenable to dispersants.

(b) Adjacent stockpiles can be used to supplement the one closest to the spill.

tractor-semitrailer had to be rented, the delivery time would be 12 to 14 hours. These times bring the dispersant to the operations base; additional time would be required to apply the dispersant to the slicks. Spills at locations greater than 260 n. mi. from a stockpile would require additional time at the rate of 3 hours for each 100 n. miles over 260 n. miles for land transport and 1/3 hour for each 100 n. miles over 260 n. miles for air transport.

3. CHOICE OF DISPERSANT

The choice of dispersant is affected by the choice of application technique and stockpile locations and sizes. It is also affected by practical considerations such as cost, availability and safety of use. Although no hard choice needs to be made at this time in Coast Guard development, certain preferred operational characteristics can be stated. These characteristics narrow down the list of suitable dispersants from an operational point of view even if attention is restricted to EPA-accepted data and manufacturer disclaimers. The desirable characteristics are:

(1) Pumpability. A dispersant should be pumpable down to 20°F at least for application in the northern U.S. and 0°F in Alaska. (volume I, Table 4) Pumping cannot take place below the pour point or below the freezing point. Only hydrocarbon-based and concentrate products have pour points below 0°F; water-based products cannot be employed in northern locations because of freezing. Since a stockpile should be available for transport and use in any part of the country, water-based dispersants are at a disadvantage.

(2) High Flash Point. Only one of the thirteen dispersants covered by the EPA-accepted data of Volume I presented a flash point substantially less than 150°F.

(3) Low Temperature Storage Stability. A suitable dispersant should undergo no adverse changes when stored for prolonged periods at low temperatures (say, 20°F in northern

(9) Significant production. This is taken as production capability of 100 or more 55-USG drums per day in the U.S. with a production lead time of 1 day or less, as of February 1980.

The logistics-related characteristics of 13 dispersants with data accepted by EPA are shown in Table 17. An x indicates that the product is undesirable relative to the characteristic, a ✓ indicates, that it is desirable from that point of view. A blank indicates either no data, or not applicable. The chart is based on EPA-accepted data or on manufacturer's disclaimers. The Pour Point and Storage Point characteristics have two levels of desirability: 0°-20°F for use in the U.S. outside of Alaska, and <0°F for use in Alaska.

From Table 17 it appears that no product has all desirable properties. Moreover, the all-important characteristics of effectiveness are not shown or fully known. However, the question of effectiveness on various crude oils, under given agitation, temperature and slick conditions are answered partly by British and Canadian tests, which cover four of the thirteen products. The results (Volume I) may be summarized as follows:

Doe (Reference 10) conducted tests in a simulated environmental tank. He defined effectiveness as the dispersant oil ratio required to disperse 65% of the test oil. He used both fresh and seawater at various temperatures. The results are:

Product No.	Temperature °C	Effectiveness on VC/S	MB/S	HB/S	VC/F
4	15	IE	-	-	IE
9	1	1:27	IE	IE	1:10
11	5	1:1	IE	-	1:3
12	5	1:27	1:1	-	1:1

where VC = Venezualian Lago Media Crude, MB = Medium Bunker Fuel, HB = Heavy Bunker Fuel, S = salt water, F = fresh water, and IE = Ineffective.

Gill (Reference 11) conducted sea trials to determine the average end-point ratio of oil/dispersant using Tia Juana crude. The results are:

Product No.	Temperature °F	End Point on Tia Juana Crude
9	62	8.5
11	62	2.9
12	62	7.8
9	40	-
11	40	2.3
12	40	6.0

If all attention is restricted to these four products, dispersant selection is almost immediate: Product 4 not only shows poor effectiveness in Doe's data, but has a very low flash point and no U.S. stockpile; Products 11 and 12 have neither production nor stockpiles in the U.S. and require agitation, although Product 12 has been used in aerial tests (see Volume I). The remaining product (#9) appears to have a high storage temperature and is not recommended by the manufacturer for fresh water use. (Both of these points required clarification; the first is inconsistent with pour point and manufacturer data, the second with Doe's data.)

The conclusions to be drawn, then, are that

- o No product has all desirable logistics-related characteristics
- o Relevant effectiveness data have been published for only four of the 13 dispersants at the present time (September 1980). Two of these (products 9 and 12) bear further investigation of their logistics-related characteristics (storage, fresh water use, aerial application)

4. FORMULATION OF STRATEGIES

The preceding results regarding vehicles, stockpiles and dispersants need to be combined into practical strategies for Coast Guard implementation. The major strategic question is the extent wing, one helicopter) and one spotter vehicle. This would allow one day's exercise with each aircraft type, plus one day of simultaneous operation. In addition, the base would procure and stock one set of nozzles for each spray aircraft, plus spares. Two full-time USCG personnel (one pilot, one pollution response officer) would provide training on a rotating basis throughout the country.

The zero-level strategy is well suited to current conditions, under which dispersant use is rarely approved.

4.2 STRATEGY 1: COMMERCIAL CONTRACTING

This strategy involves standing basic ordering agreements with commercial organizations executed by MSO or COTP offices, for use by the OSC. It is assumed that 11 offices nearest the sites listed in Table 9 each carry out the strategy as follows (see Table 18):

1. Small fixed wing or helicopter aircraft of at least 100 gallon capacity equipped with suitable nozzles (see Volume I), to be available at the relevant USCG station within a specified time. The delivery time and number of aircraft would vary with local conditions but 1 to 2 small fixed wing aircraft available from each contractor in 12-24 hours is not an unreasonable goal of negotiation. Helicopters such as the B206 are not always available on short notice; a one-day availability is common. Both fixed wing and helicopters should be contracted for since they are suitable for different regimes (see Figure 19). These should be "wet" contracts, i.e., they should include dispersant, because (a) the contractor is usually better able to store dispersant than the MSO, (b) it will generally reduce the response time, since loading can be done more rapidly by the contractor using his own facilities. The Coast Guard, of course, must specify the dispersant. Enough dispersant should be stockpiled by the contractor in 55 USG drums for 20 sorties of each aircraft. (This is about 11,200 liters

for the Pawnee, and 6,000 liters for a Bell 206B, enough for 1 day's operation.) However, in order to reduce dispersant costs, if more than one aircraft of each type is contracted, the stockpile should be distributed among contractors for the type, with provision for truck transport to the operations base when needed. Storage temperature and conditions must be specified as well. If a Coast Guard helicopter is not stationed at the base, the contracts should call for at least one spotter aircraft, available at the same time as the spray vehicle.

2. Periodic training exercises. These should be part of the local contingency plan, and should involve EPA as well as Coast Guard and contractor personnel. In addition to local contracts, national contracts servicing all MSO/COTP areas would be negotiated as follows (see Table 18):

3. Large fixed-wing aircraft such as DC-4 or DC-6 equipped with suitable nozzles to be able at pre-selected operations bases within specified times. While full-year 24-hour retainer fees are high (see Table 4B) a more reasonable service charge is usually levied for 1 to 3 day delivery. Standing as-required contracts should be negotiated with as many firms as possible (i.e. with both Globair and Conair) so as to obtain minimum available delivery time. The contracts should include crews and fuel, but no dispersant i.e., 'dry'.

4. Dispersant purchase orders from the manufacturers. If it is assumed that the dispersant of choice is domestically stored concentrate (product 9) then the stockpiles presently available amount to about 170 tons, or enough to treat about 3.4% of the "dispersable" oil. (To this must be added the amount of dispersant stored under local 'wet' contracts, plus amounts that can be produced). Contracts should provide a standing order of a minimum of 100 tons of dispersant in 55-USG drums delivered by truck

stockpile). The average travel time between base pairs in the 48 states is 10.7 hours, which brings delivery to about 12 hours, assuming pre-loaded tractor-trailers.

With the assumption of USCG-owned and maintained stockpiles at the 11 bases, each stockpile of 70 drums can be reduced by half. But storage costs and transport costs would be added. A 35-drum stockpile easily fits on one low-bed semitrailer with a pump for aircraft loading. It will be assumed that at least one tractor is available for pollution response at each base. The low-bed semi-trailer, however, would have to be purchased and pre-loaded with dispersant; estimated cost of semi-trailer is $7500. Storage space (heated) is estimated at $2000 per year, off-base. The reduction in initial cost will be seen to be about $150K, over 11 bases, but the annual cost will increase by $22K per year.

Both Strategy 1 and 1A involve an outlay of Coast Guard funds of sufficient magnitude that the projected frequency of use of dispersants becomes an important factor in strategy selection.

4.4 STRATEGY 2: COMMERCIAL CONTRACTING PLUS USCG HH3-F

The availability and response times of the USCG HH3-F are generally superior to those of commerical contractors of small fixed and rotary wing vehicles. Normalized application costs are comparable. In this strategy, the USCG HH3-F would be employed instead of commercial contracts within the 250 n. mi. range of the Direct One-Way mission. These areas are enclosed in the dashed circles of Figure 20. This would eliminate all commercial contracts at the eleven spill response bases of Table 9 except those of San Francisco. Supplementary contractors may be arranged for Corpus Christi TX and Honolulu HI for complete coverage of the U.S. (see Table 19).

This strategy, however, does not reduce the requirements for stockpiles at the 11 bases. The stockpiles for 1 day's operation of the HH3-F is about 15,000 liters (70 drums) under good slick conditions (Figures 4 through 7), somewhat more than for the Piper Pawnee's 11,200 liters, so that the stockpiles at the 11 bases would be greater in toto. In addition, stockpiles would be placed at Clearwater FL, Aguadilla, PR, San Diego, CA, and Sitka, AK. The Bay St. Louis stockpile would be located at New Orleans and the Los Angeles stockpile at San Diego. Each stockpile (about 70 55-USC drums) would be transportable by a single 40 foot semi-trailer or by two low-bed trailers. Single-mission (3 55-USG-drum) stocks would be located at Otis AFB, Kodiak, AK, and Astoria, OR.

The requirement for training exercises would be met in much the same way as in Strategy 1, except that contract equipment and personnel would not be involved except at San Francisco, Corpus Christi, and Honolulu. The nine USCG HH3-F bases would each exercise once/year, two helicopters being involved in each exercise. One full time training team of two men would circuit the nine bases once per year, spending one month to train 2 men at each base. The other three months would be employed to train the three contractors.

The large fixed-wing aircraft and dispersant purchases from the manufacturer would be the same as in Strategy 1.

4.5 STRATEGY 2A: CONTRACTS PLUS USCG HH3-F (REDUCED)

The deployment of Strategy 2 can be reduced so as to make its coverage comparable to that of Strategy 1. This is done in Table 20. USCG stockpiles are eliminated at Aguadilla, and Sitka; they are reduced at Clearwater and San Diego; contractors are eliminated at Corpus Christi and Honolulu; HH3-F support is removed at Aguadilla and Sitka. These reductions are reflected in lower stockpile costs and lower training cost.

4.6 STRATEGY 3: CONTRACTS USCG HH3-F, 1000-TON USCG STOCKPILE

This strategy is the same as Strategy 2, except that commercial manufacturer's stockpiles are supplemented by a large-scale USCG stockpile. As seen in Figure 21, a total of 2,500 tons

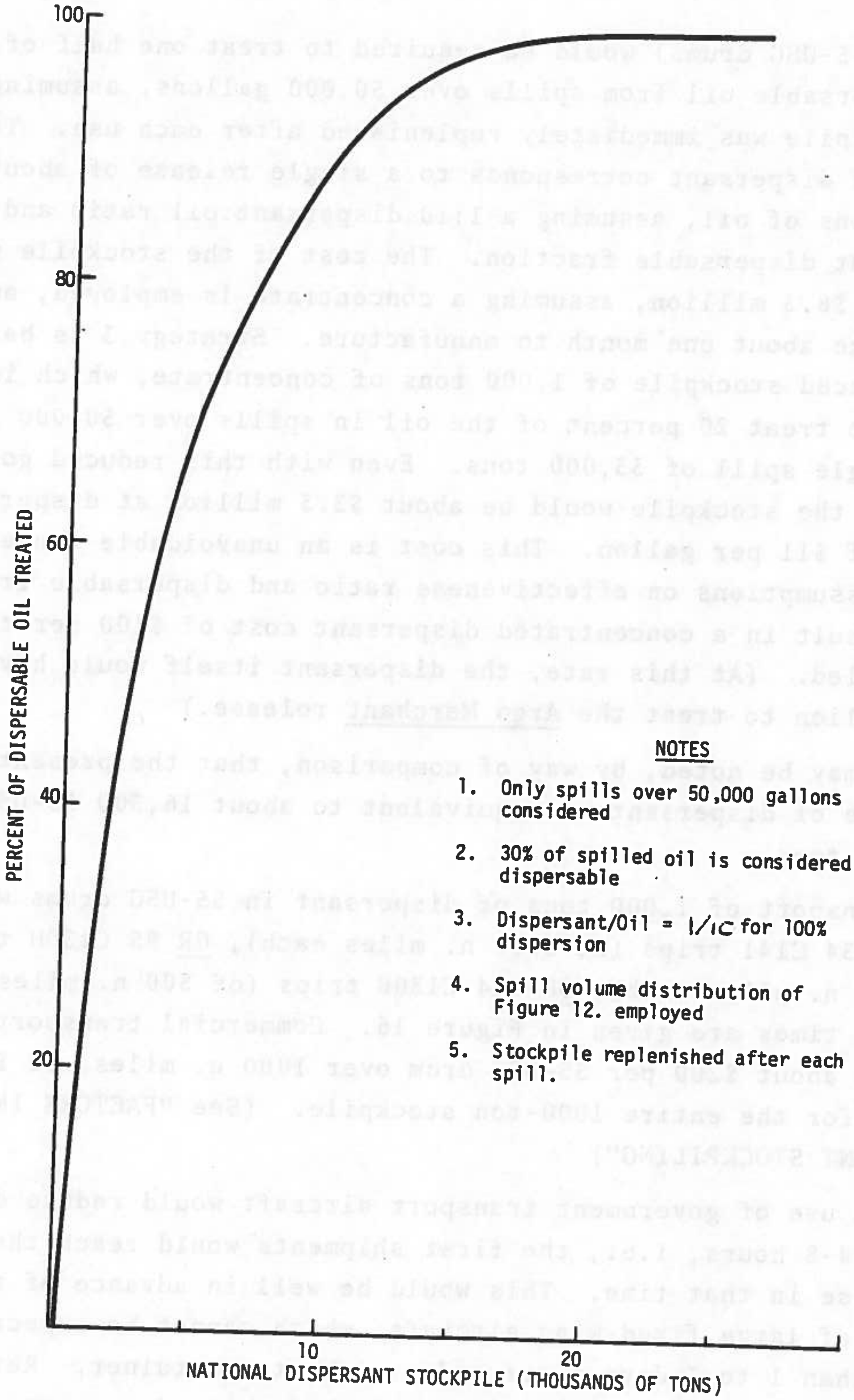

FIGURE 21. PERCENT OF DISPERSABLE OIL THAT CAN BE TREATED AS A FUNCTION OF SIZE OF STOCKPILE

therefore, would provide excellent response to a large spill until more large fixed-wing aircraft can be contracted.

The large financial commitment implied in this strategy makes it practical only if EPA policy regarding the use of dispersants is such as to make their widespread use likely. In particular, the likelihood of dispersant use on large-size (10,000-100,000 tons) crude oil spills would have to be ascertained because the major investment in Strategy 3 is in dispersant stockpiles required for such spills.

Stockpiling of 1,000 tons of dispersant by the U.S. Coast Guard, in addition to the deployment of Strategy 2, will be designated as Strategy 3.

STRATEGY 3A. If the 1,000 ton stockpile is added to Strategy 2A, there results Strategy 3A.

STRATEGY 4: Contracts, USCG HH3-F, and 2,500 TON USCG Stockpile. If the USCG-owned stockpile in Strategy 3 is set at 2,500 tons of dispersant, then there results Strategy 4.

5. EVALUATION OF STRATEGIES

The strategies just outlined will be evaluated with regard to response time, initial and annual cost, cost per spill, and implementation time.

Initial and Annual Costs

For purposes of estimation, dispersant costs will be taken to be $11 per USG, corresponding to current (September 1980) prices for domestically produced concentrate. The costs to be estimated are the incremental costs over presently planned expenditures for pollution response. In particular, they will be calculated on the assumption that 11 USCG pollution response bases will be established as in Table 9, and that USCG aircraft will be maintained for other missions as well as pollution response. USCG aircraft costs will be included only for dispersant-specific missions and training. Dispersant storage is calculated at $5/square foot up to 5,000 square feet, and $2.50/square foot above that. The costs of the various strategies are shown in Table 21.

TABLE 21. INITIAL AND ANNUAL COSTS FOR STRATEGIES 0 THROUGH 4 (CONTINUED)

Type	Size	Source	Availability Time	Number	Initial Cost	Cost per Yr.	USCG M-Y/year
STRATEGY 2: CONTRACTS PLUS USCG HH3-F (CONTINUED)							
Dispersant	620 l.	USCG	1 hr	3	5	0	0
Dispersant	11,2001.	Contract (2)	1-2 hr	3	98	0	0
Dispersant	3,440 l.	Contract (2)	1-2 hr.	3	30	0	0
Semitrailer	40 feet	USCG	0 hrs	14	140	0	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0
Exercises	3-day	USCG	-	9/yr	0	216	3.
Exercises	3-day	USCG	-	3/yr	0	75	0.5
					1011	319	4.5
STRATEGY 2A: CONTRACTS PLUS USCG HH3-F (REDUCED)							
HH3-F	Medium	USCG	1-5 hrs	14	98 (6)	0	0
Fixed Wing	Small	Contract (2)	6-24 hr	2	0	0	0
Helicopter	Small	Contract (2)	12-24 hr	2	0	0	0
Fixed Wing	Large	Contract	1-3 days	3	0	0	0
Dispersant	15,000 l.	USCG	1-6 hrs	10	437	20	1.
Dispersant	620 l.	USCG	1 hr	5	8	0	0
Dispersant	11,200 l.	Contract (2)	1-2 hr	1	33	0	0
Dispersant	3,400 l.	Contract (2)	1-2 hr	1	10	0	0
Semitrailer	40 ft	USCG	0 hr	10	100.	0	0
Dispersant	100 tons	Contract	2-4 days	1	0	0	0
Exercises	3-day	USCG	-	7/yr	0	168	3
Exercises	3-day	USCG	-	1/yr	0	25	0
					686	213	4

NOTES TO TABLE 21.

(1) Based on 12 hours small fixed wing, 12 hours small helicopter, 24 hours HH3-F; see Table 4B.

(2) Contract includes aircraft and dispersant for 20 sorties. Contract cost taken to be equal to dispersant cost plus actual aircraft time. Dispersant storage is assumed to be a no-charge condition of contract.

(3) Storage cost.

(4) Dispersant plus semi-trailer.

(5) Two full time travelling trainers, 3 trainees per base, one month each per year.

(6) Cost of bucket spray gear.

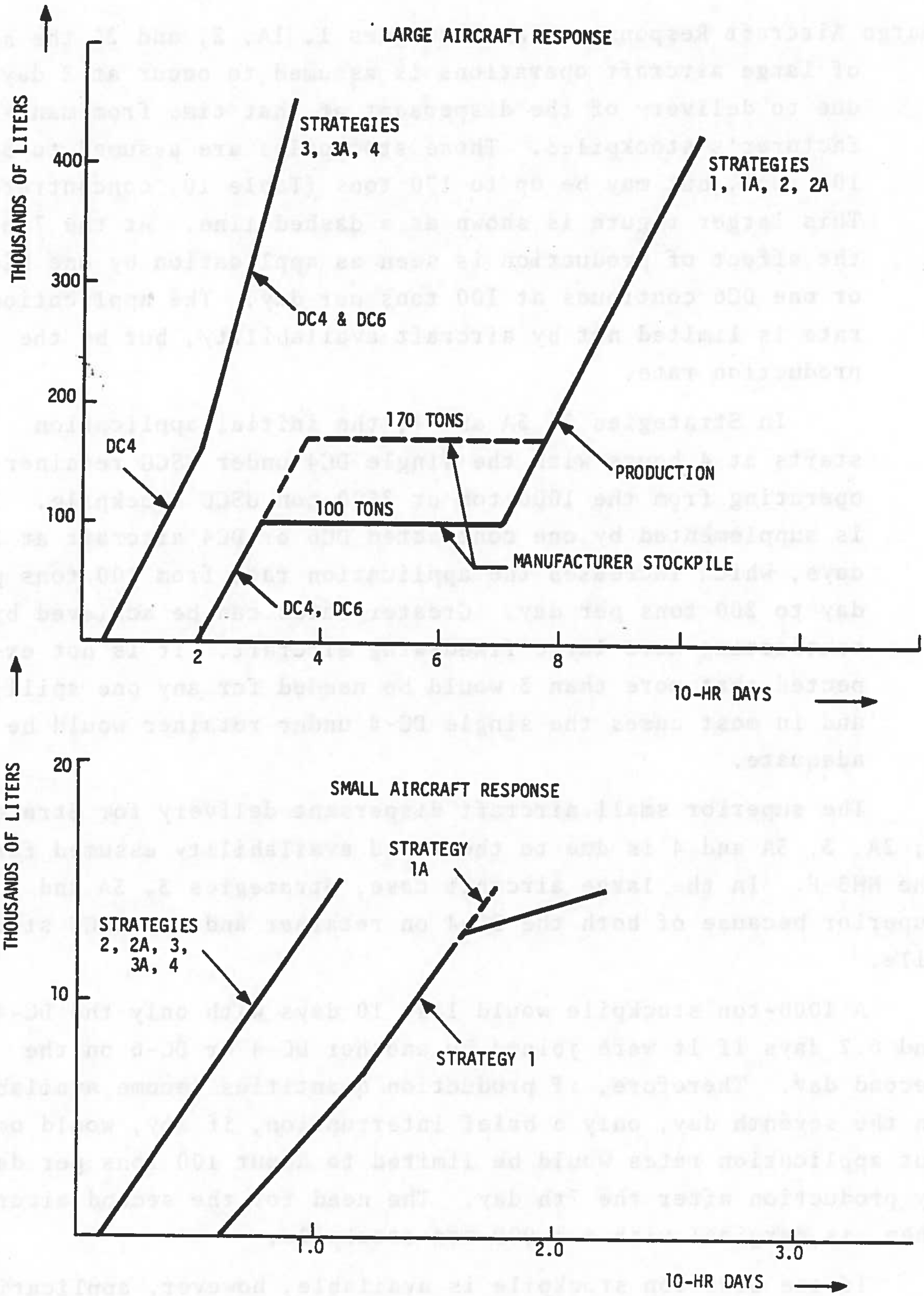

FIGURE 22. DISPERSANT DELIVERY SCENARIOS
FOR LARGE AND SMALL AIRCRAFT

to 100 tons per day. Thus, after the 20th day, only one aircraft would be required, although the second would probably be held on retainer as backup.

The application tonnage achievable by two large aircraft under Strategies 3, 3A and 4 are illustrated in Figure 23.

<u>Cost per Spill</u>

The cost per spill is determined primarily by the spill size and by the application vehicles employed, and secondly by distance from base to slick, mean pass length, areal density and slick/pattern ratio. Two cases will be assumed:

	Small Spill	Large Spill	
Volume	200	20,000	thousand liters
Distance	5	50	km
Vehicles	SFW, SHC	LFW	
Pass Length	0.6	4.0	km
Areal Density	45	45	liters/hectare
Slick/ Pattern	0.5	0.5	
Dispersant Cost	11.00	11.00	$/gallon
Dispersant Vol.	6,000	600,000	

If the small spill is treated by a Pawnee or Bell 206B, the costs would be:

	Pawnee	Bell
aircraft rental (spray)	$3,000	$11,100
aircraft rental (spotter)	3,000	11,100
aircraft ferry	200	350
aircraft overnight retainer	0	1,800
dispersant at $11/USG	17,490	17,490
	$23,690	$41,840

The dispersant costs would be incurred to replenish the contractor or USCG stockpiles. The costs of USCG and support personnel are not included. In practice the spill may be treated partly by each aircraft, so that the cost would be between $21,000 and $29,000. The spotter is assumed to be a contractor vehicle of the same type as the spray vehicle. If USCG aircraft are used for spotting, this cost would be different (not necessarily less).

If the large spill is treated by a contracted DC6 (not on retainer) the costs are estimated as follows:

Aircraft Type Time on Site	DC4 8.6 days
aircraft ferry (3 hrs each way)	$9,900
aircraft rental (spray)	144,000
aircraft overnight retainers	38,000
dispersant at $11/USG	1,749,000
spotter aircraft	43,000
transport of dispersant*	58,000
	$2,041,900.

(*$200/drum over 1000 n. mi. See text preceding.)

The spotter aircraft is assumed to be a USCG HH3-F. In this case, it is less expensive than the B206 or Pawnee because it does not require a retainer. Again, the dispersant cost is that of replenishing the stockpile, under Strategy 3, 3A, and 4, or of purchasing directly from the manufacturer under Strategy 0, 1, 2, 2A.

Implementation Time

The various strategies differ in the length of time required to plan, purchase, produce and deliver the equipment and to achieve full training capability. Table 22 shows the implementation time for the various strategies. Times are measured from start of program, and do not include program planning time or budget cycle times.

It is possible, of course, to mix strategies.

TABLE 22. IMPLEMENTATION TIMES FOR VARIOUS STRATEGIES, MONTHS (CONTINUED)

STRATEGY 2A:

(a)	Negotiation of small aircraft contracts	4
(b)	Large Fixed Wing contract	6
(c)	Dispersant acquisition by contractors	1
(d)	Dispersant acquisition by USCG	6
(e)	Semitrailer acquisition by USCG	12
(f)	Dispersant stockpiles (manufacturer)	0
(g)	Exercises/Training	8
	Net Time, (e) + (g)	20

STRATEGY 3:

Same times as Strategy 2, plus:

(h)	Contract and acquisition of USCG stockpile (1000 tons)	12
(j)	Retainer contract for DC4	8
	Net Time, (e) + (g)	20

STRATEGY 3A:

Same times as Strategy 2A, plus:

(h)	Contract and acquisition of USCG stockpile	12
(j)	Retainer contract for DC4	8
	Net Time, (e) + (g)	20

STRATEGY 4:

Same as Strategy 2	20

REFERENCES

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CONVERSION FACTORS

Multiply	By	To Get
Gallons (US)	0.00378	Cubic Meters
Gallons (US)	3.785	Liters
Barrels (US)	6.668	Cubic Meters
Feet	0.3048	Meters
Inches	25.400	Millimeters
Feet/minute	0.0183	Kilometers/hour
Feet/minute	0.3049	Meters/minute
Feet/second	1.097	Kilometers/hour
Feet/second	18.283	Meters/minute
Knots	1.8532	Kilometers/hour
Square Feet	9.29×10^{-6}	Hectares
Acres	0.4047	Hectares
Square miles	2.59	Square Kilometers
Square miles	259.00	Hectares
Acres	0.004049	Square Kilometers
Gallons (US)/acre	9.353	Liters/Hectare
Cubic Meters	264.55	Gallons (US)
Liters	.264	Gallons (US)
Cubic Meters	1.50	Barrels (US)
Meters	3.281	Feet
Millimeters	.0394	Inches
Kilometers/hour	54.6	Feet/minute
Meters/minute	3.281	Feet/minute
Kilometers/hour	.912	Feet/second
Meters/minute	.055	Feet/second
Kilometers/hour	.5396	Knots
Hectares	1.076×10^{5}	Square Feet
Hectares	2.471	Acres
Square Kilometers	2.59	Square Miles
Hectares	259.00	Square Miles

APPENDIX I
ADAPTATION OF SAR PATTERNS TO DISPERSANT APPLICATION

Reference "National Search and Rescue Manual," CG-308 and Amendments Am-1, Am-2, Am-3.

Despite substantial differences between Search and Rescue (SAR) and oil spill dispersant application, the SAR patterns of the reference can be adapted in part to dispersant application. The intent in both mission types is to cover as much area in as short a time as possible. The basic SAR relationship

A = VSNT

applies to both missions,

where A = area covered
V = vehicle speed in search or spray
N = number of vehicles
S = track spacing, swath width
T = time in search or spray.

The following comments are intended to guide the adaptation of the 33 SAR patterns of the Reference to oil dispersant application.

1. Trackline Patterns (TSR, TMR, TSN, TMN)

These patterns are oriented along the intended track of the target. They are adaptable to vessel application of dispersant when the slicks are elongated. They are not well adapted to aircraft application if there is a wind and if the slick is not aligned with the wind. Another difficulty in use by aircraft is that the ratio of sweep width/turning radius is much smaller for dispersant application than for SAR. This has two effects:

(2) Aircraft spacing would have to be too tight to allow use of the multiunit patterns TMR and TMN, without extremely tight aircraft-aircraft coordination.

CM is to difficult for aircraft to execute safely in dispersal of oil. The coordinated patterns, in which a vessel coordinates aircraft movement, are not of use in dispersant application, since the slick is more visible form the air than from the vessel.

4. Square Pattern (SS,SM)

The single-vehicle square pattern SS cannot be executed for dispersion by fixed wing aircraft and is difficult for helicopters. It is more practical for vessels. But a contracting square pattern, i.e., one in which the vehicle spirals in to the center, is also suited to dispersant application by a single vehicle because (a) the time for a circuit, at least initially, is greater and this allows more time for the dispersant to have an effect, making it easier to lay successive tracks accurately, i.e., to avoid overlapping; and (b) it works from the edge of the slick inward, thus inhibiting its spread.

Variations of the SM pattern can be devised that are suitable for vessels, but not for aircraft.

5. Sector Patterns (VS, VM, VSR, VMR)

These patterns are not only less efficient, but when used for oil dispersal can result is heavy overdoses at the center. They should be avoided for that reason. Further, they are not suitable for aircraft application in a wind, because of the continually changing headings.

The most likely circumstances in which the Sector Patterns may be usefull in dispersant application is that of one or more vessels with adjustable rate pumping systems operating in an area in which parallel, square, or creeping line patterns are not possible.

The radar-controlled patterns VSR and VMR offer no advantage for dispersant application, and in fact, are substantially useless for that purpose because of the limited radar accuracy.