The Case for Using Vessel-Based Systems to Apply Oil Spill Dispersants

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Abstract

The paper compares the capabilities of aircraft-based dispersant application systems and vessel systems and concludes that vessel-based systems have certain advantages, including better availability and cost, better spray control and accuracy, ability to dose thick slicks in one pass, and ability to treat spills as quickly as aircraft under certain circumstances. The recommendation is to design, test and make operational modern vessel-based dispersant systems based on the most promising application approach that exists today, namely the use of fire monitors.

1.0 Introduction

Most contingency plans for dealing with marine oil spills include the option of using chemical dispersants. In these plans, the application platform is invariably an aircraft system. Although vessel-based systems were the norm in the early days of dispersant use, the general view now is that their use is out-dated and inappropriate for most spill situations. This paper presents another view, which is: Although large aircraft systems are superior to vessel systems in many instances, vessels can still play an important role in responding to many spill situations.

Large aircraft for dispersant application are not widely available, and stand-by fees to make them available on short notice can be relatively large. On the other hand, vessels appropriate for dispersant use are relatively inexpensive, are more readily available, and are already an integral part of oil spill response capabilities around the world. Such vessels need not be sophisticated; the major requirement is that they have reasonable storage space for dispersant product. They must also be within reasonable transit time to spills, but this will frequently be the case because marine spills usually occur in restricted, high-traffic waters; these are often close to ports that are home to vessels.

The main complaint about vessels is that they are too slow, both in reaching spills and in treating them, especially when compared to the capabilities of aircraft systems. One purpose of this paper is to analyze whether this complaint is valid in view of current knowledge. The basic question is whether there is a role for vessel-based dispersant application systems in the treatment of fairly large spills.

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1 This paper was presented at the 21st Arctic and Marine Oilspill Program Technical Seminar held in Edmonton, Alberta, on June 10 to 12, 1998. Some minor changes have been made to the paper.
2.0 The Importance of Slick Spreading on Dispersant Application

To fully appreciate the advantages of vessel-based dispersant application systems compared with aircraft-based systems, it is important to understand how knowledge of oil-slick spreading has changed over the years, and how this has influenced our understanding and design of spill dispersing systems.

2.1 Earlier Views

It is generally understood that marine oil spills spread quickly and that response with cleanup systems must be very quick. The fast rate of oil spill spreading is demonstrated in Figure 1, which is a version of a figure first developed in the late 1970s (Mackay et al. 1980) and still used extensively in industry contingency plans in North America today. The figure can be used to show that for a spill of, say, 1000 m$^3$ (6300 barrels) the total slick area reaches about 10 km$^2$ in one or two days of spreading, and this is equivalent to an average slick thickness of 0.1 mm. This average thickness value of 0.1 mm is mentioned often in the dispersant literature in the 1970s and 1980s as the thickness to consider in the design and implementation of a dispersant response operation.

![Figure 1 Total Slick Area for Various Spill Sizes as a Function of Time](image-url)
This view that spills should be dispersed when they reach a uniform thickness of 0.1 mm led to the concept of a one-pass (carpet-sweeping-like) mode of dispersant application (Lindblom 1979, 1981; Exxon 1992, Allen and Dale 1995). A one-pass application becomes possible because a large aircraft system can apply enough dispersant in one pass to treat about 0.10 to 0.30 mm of slick at a dispersant-to-oil ratio (DOR) of 1:20. This means that a large aircraft system can theoretically dose a fairly large spill (spread out with uniform thickness of 0.10 mm) in a reasonable period of time. In this concept, almost all flying time at site is spent in spraying the slick and not in repositioning and turning around because the slick is considered to have a very large area (tens of square kilometres for large spills). Considering the same large, uniformly-thin slick, the use of vessels for applying dispersant is less attractive because the slick would take more than ten times longer to treat. This is because vessels travel at less than one-tenth the speed of large aircraft. This means that one application vessel with a small payload, shuttling between the spill and the dispersant supply base, could theoretically take weeks to treat even a medium size offshore spill. This, of course, would be unacceptable.

The above line of thinking has led to the selection of aircraft over vessels for applying dispersant, especially on large spills, as evidenced in most contingency plans today.

2.2 Targeting the Thick Part of Spills

Despite the above notions, it has been known for some time that marine spills do not spread uniformly. Rather, oil spills are composed of thick patches (usually thicker than 1 mm) that contain most of the spill's volume and that these patches are surrounded by sheens (about 1 to 10 $\mu$m or 0.001 to 0.01 mm). The areas noted in Figure 1 represent the total area of thick patches and sheen.

The phenomenon of thick/thin spreading is widely accepted today, and there is much remote sensing and photographic imagery to support this. Although there is little quantitative information available on actual, large spills, some very well documented experimental spills have involved measurement of either thickness or volume plus area (Mackay and Chau 1986, Lunel and Lewis 1993, Lewis et al. 1995, Walker et al. 1995, Brandvik et al. 1996, Lewis et al. 1998, Davies et al. 1998). These indeed show that oil spills at sea, even small ones, do tend to stay relatively thick (> 1 mm) for many hours.

It is clear that if the entire slick (thick and thin portions) is sprayed uniformly by aircraft as proposed in the old approach, the thicker portion will be underdosed and the sheen overdosed. This happened in many actual oil spills and field trials and certainly occurred in a well-documented trial that was conducted in Norway in 1985, as discussed by Mackay (Mackay and Chau 1986, Chau and Mackay 1988) and summarized in Table 1.

Notice that the dispersant-to-oil ratio for the thick portion of oil (representing the vast majority of oil spill volume) was only 1-to-73. This is much less than the recommended 1-to-20. So the results of the trial were bound to be less than ideal. On the other hand, the dispersant-to-oil ratio for the sheen was almost 1 in 1, representing an excessive dosage and waste of dispersant product.

This more realistic view of slick spreading — that spills are generally composed of relatively small areas of thick oil surrounded by large areas of very thin oil — calls for a reassessment of the use of vessels for dispersant application, as explained by the following example. Again, consider a spill of 1000 m³ (6300 barrels) that has been on the water surface for
about 10 hours. From Figure 1, this will have a total area of thick oil and sheen of about 5 km².

Table 1  Over-Under-Dosing for the 1984 Norwegian Experimental Spill\(^1\) Assuming 400 μm Diameter Dispersant Drops

<table>
<thead>
<tr>
<th></th>
<th>Thick Slick</th>
<th>Sheen</th>
<th>Entire Spill</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slick Volume (m(^3))</td>
<td>9.72</td>
<td>0.28</td>
<td>10</td>
</tr>
<tr>
<td>Slick Area (m(^2))</td>
<td>4510</td>
<td>27690</td>
<td>32200</td>
</tr>
<tr>
<td>Slick Thickness (mm)</td>
<td>2.16</td>
<td>0.01</td>
<td>0.31</td>
</tr>
<tr>
<td>Fractional Areas</td>
<td>0.14</td>
<td>0.86</td>
<td></td>
</tr>
<tr>
<td>Dispersant Applied (m(^3))</td>
<td>0.133</td>
<td>0.311</td>
<td>0.444</td>
</tr>
<tr>
<td>Dispersant Fractions Applied</td>
<td>0.3</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Oil to Dispersant Ratio</td>
<td>73.0</td>
<td>0.89</td>
<td>22.5</td>
</tr>
</tbody>
</table>

1. Reference: Daling and Lichtenhaler 1985
   Source of Table: Mackay and Chau 1986 (also in Chau and Mackay 1988)

The current rule of thumb is that 90 to 95% of the total spill volume is in 5 to 10% of the spill area. This means that the thick portions of the spill, after allowing for evaporation, would have an average thickness of about 2 mm and an area of about 0.4 km² (100 acres or 40 hectares). If an aircraft were to treat the thick oil portions of this spill it would take many passes to do so, because the thickness of slick that current aircraft systems can completely treat per pass (at a DOR of 1:20) is only about 0.1 to 0.3 mm, which is equivalent to a dispersant dosage of about 50 to 150 L/ha (5 to 15 gallons per acre). It can be shown, on this basis, that the aircraft would spend most of its time repositioning itself and not spraying. Although each pass over the thick oil would take only seconds, the positioning would take up to a few minutes depending on the shape of the spill and the turnaround pattern of the aircraft (180° or 360° turns). These minutes add up when considering there must be many repeat passes to treat the spill in question. This does not mean that the operation is not possible, but rather that it is not as quick and efficient as implied by the 0.1 mm slick/one-pass method discussed above.

The main point is that for the example spill described above, the use of vessels now makes sense in many ways. For one, the target slick area is now less formidable. For the 1000 m\(^3\) spill discussed above, the thick portions might have a total area in the order of 0.4 km². It can be shown that a vessel traveling at about 10 knots with a spray swath of about 25 metres can completely treat these thick portions in about 50 minutes, plus the time needed to move from thick patch to thick patch. This is not very different than the time needed by the aircraft to treat the same spill (time mostly spent in repositioning). Another important advantage of the vessel-
based approach is that thick portions of a spill can be treated in a single pass, whereas the aircraft must use several passes, each time positioning itself to hit the same oil again and again until the slick is completely dosed. This is a difficult task operationally. For the vessel, because its speed through the slick is relatively slow, only a modest sized pump and spray boom width are necessary to completely dose even relatively thick slicks. For example, a vessel traveling at 10 knots, having a spray swath of 25 m, and a dispersant pump capacity of 760 L/min (200 gpm), can totally dose a 2-mm thick slick in one pass at the recommended DOR of 1-to-20. If the slick is thicker, the vessel can slow down to achieve an even higher dose rate.

Although both aircraft and vessel-based methods of slick treatment would require the use of overflying spotter aircraft to guide the operation, it is reasonable to believe that the vessel-based operation would be more efficient and have more control in treating identified target slicks.

In summary, from the point of view of application alone, vessel-based dispersing systems appear to offer certain advantages over aircraft-based systems for certain spill situations. The question remains whether the logistical aspects of the response still largely favor the use of aircraft for most spill situations. By logistics we mean the whole process of moving application platforms to the staging area and then back and forth between the base of operations and the spill site. That is the subject of the next section.

3.0 Logistics Exercise

The purpose here is to compare vessels to aircraft in terms of the logistics of treating offshore spills. Before proceeding with the comparison, it is useful to consider briefly the sizes and locations of historical tanker spills.

3.1 Focus on Spill Size and Location

It is natural to worry about extremely large tanker spills that occur far offshore, but most tanker spills tend to occur relatively close to land, primarily as a result of collisions and groundings. Such spills on average are not immense, but are large enough to cause severe damage if they come ashore. It is suggested that such spills should be the focus of a vessel-based, dispersant-use planning program.

There is a reasonable database on historical tanker oil spills that can be used to analyze the frequencies and locations of spills. The U.S. Minerals Management Service (MMS) has studied worldwide tanker spill statistics in depth and developed a simple approach for predicting spill frequency (Anderson and Lear 1994, Anderson and LaBelle 1994). Table 2 shows worldwide oil spill frequencies calculated by Anderson and LaBelle (1994) for three different spill-size categories. (Note that the category of >1000 bbl includes the other two categories).

For our purposes it is of interest to break down the at sea statistics in Table 2 into the categories of restricted waters defined as waters less than 50 nautical miles from land (93 kilometers) and spills in the open sea, that is, beyond 50 n. miles from land. The analysis is limited to spills larger than 1000 barrels. Table 2 shows that 136 such spills occurred at sea (restricted waters and open sea) during the time frame of 1974 to 1992.

In Anderson and Lear (1994), accident locations are noted for the spills in the database. So it becomes possible to categorize the large at sea spills (>1000 bbl) appropriately and to determine average spill sizes for the new categories. Table 3 summarizes the reworked version of
Table 2 including average spill sizes. It is seen that of the 136 *at sea* spills, 26 spills or 12% occurred in the open sea, and 88% occurred relatively close to land.
### Table 2 Worldwide Tanker Spill Rates, 1974-1992

<table>
<thead>
<tr>
<th>Tanker spills&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Number of spills</th>
<th>Average spill size (bbl)</th>
<th>Median spill size (bbl)</th>
<th>Spill Rate&lt;sup&gt;b&lt;/sup&gt; (spills per 10&lt;sup&gt;9&lt;/sup&gt; bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≥1000 bbl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Port</td>
<td>77</td>
<td>58,300</td>
<td>6400</td>
<td>0.47</td>
</tr>
<tr>
<td>At Sea</td>
<td>136</td>
<td>130,100</td>
<td>22,000</td>
<td>0.83</td>
</tr>
<tr>
<td>All Spills</td>
<td>213</td>
<td>104,200</td>
<td>15,000</td>
<td>1.30</td>
</tr>
<tr>
<td>≥10 000 bbl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Port</td>
<td>31</td>
<td>139,500</td>
<td>50,000</td>
<td>0.19</td>
</tr>
<tr>
<td>At Sea</td>
<td>88</td>
<td>198,700</td>
<td>88,400</td>
<td>0.53</td>
</tr>
<tr>
<td>All Spills</td>
<td>119</td>
<td>183,300</td>
<td>73,300</td>
<td>0.72</td>
</tr>
<tr>
<td>≥100 000 bbl</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In Port</td>
<td>12</td>
<td>310,300</td>
<td>251,000</td>
<td>0.07</td>
</tr>
<tr>
<td>At Sea</td>
<td>40</td>
<td>392,900</td>
<td>243,600</td>
<td>0.24</td>
</tr>
<tr>
<td>All Spills</td>
<td>52</td>
<td>373,800</td>
<td>243,600</td>
<td>0.31</td>
</tr>
</tbody>
</table>

<sup>a</sup> Crude oil spills only, excludes barge and inland spills (1 bbl = 0.159 m<sup>3</sup>).  
<sup>b</sup> Based on movement of 164.4 x 10<sup>9</sup> bbl crude oil.  
Source of table: Anderson and LaBelle 1994

### Table 3 Worldwide Tanker Spill Rates for Large Spills (>1000 bbl) in Port, Restricted Waters and Open Sea, 1974-1992

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of spills</th>
<th>Average spill size (bbl)</th>
<th>Spill rate (spills per 10&lt;sup&gt;9&lt;/sup&gt; bbl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In Port</td>
<td>77</td>
<td>58,300</td>
<td>0.47</td>
</tr>
<tr>
<td>Restricted Waters (&lt; 50 n. miles)</td>
<td>110</td>
<td>122,000</td>
<td>0.67</td>
</tr>
<tr>
<td>Open Sea (&gt;50 n. miles)</td>
<td>26</td>
<td>198,000</td>
<td>0.16</td>
</tr>
<tr>
<td>All Locations</td>
<td>213</td>
<td>104,200</td>
<td>1.30</td>
</tr>
</tbody>
</table>
Because most tanker spills involve groundings and collisions, it can also be assumed that most occur in waterways close to port areas. This is because these areas generally have restricted waters and high ship traffic. Oil spill response organizations usually base their operations in these high-risk port areas. These are the areas in which one is most likely to find available vessels for a dispersant-response operation. In other words, vessels for potential use in a dispersant operation can generally be found near potential spill locations.

This is not necessarily the case for aircraft. Oil spill contingency plans that include the use of large aircraft must often allow for considerable time for the craft to arrive at staging areas near the spill site, and to mobilize generally. This would not be the case for vessels located near spill sites, which could be loaded and dispatched at once to reach spills within hours.

Therefore, in terms of mobilization time and time to reach a spill site initially, large aircraft do not necessarily offer advantages over vessels. Rather, the major advantage might be the ability of large aircraft, once mobilized, to conduct numerous sorties with large loads of dispersant to properly dose the spill within reasonable time. One might think that this surely can be faster done by aircraft than slow-moving vessels. This is not necessarily the case, as the following analysis shows.

### 3.2 Scenarios for Comparing Existing Systems

A detailed study of dispersant issues in Alaska, including dispersant-application logistics, was recently completed by SL Ross (1997), so it is convenient to use the results of that study here. The situation in Alaska is not necessarily representative of the situation elsewhere because the state has the largest stockpile of dispersant in the U.S. and two C-130 aircraft systems readily available. Nevertheless, there are lessons to be learned from the Alaskan example that are of importance generally.

There are 100,000 gallons (380,000 L) of Corexit 9527 stockpiled in Alaska (almost 30 percent of the total amount in the country). There are two C-130 aircraft systems available for dispersant use, two dedicated helicopter systems and three dispersant application vessels (Alyeska 1995). Table 4 summarizes the specifications for these systems (in US units). Notice that the vessel-based system has a very low payload and very low dispersant pump rate (12 gpm or 45 L/min). This system (from Frank Ayles & Associates Ltd.) is typical of existing systems in the U.S. and elsewhere. The pump rate is low because the system has been designed to deal with the 0.10 mm uniform slick thickness mentioned earlier. That is, if a vessel carrying the 90-foot (30 metre) spray boom moves through a spill area spraying dispersant at the rate of 12 gallons per minute, a slick that is 0.1 mm thick would get dosed at a dispersant-to-oil ratio of 1-to-20. Because we now wish to target slicks for dispersing that are much thicker than 0.1 mm, the pump rate of dispersant should be greatly increased (by a factor of 10 or more) to deal with actual needs. For the moment, let us consider the system as it now is configured, and compare it to the aircraft systems.

Note in Table 4 that the aircraft repositioning times assume the use of 180° turns. If 360° turns are considered instead, the repositioning times must be doubled approximately. Note that

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1. This analysis is only valid for the situation that existed in 1995 (Alyeska 1995). The vessel-based dispersant capability in Alaska has been upgraded since then.
the repositioning time for the vessel is taken to be zero. This is based on the assumption that vessel U-turns are unnecessary in a large slick area (Spiltec 1986). This is certainly the case

Table 4 Specifications on Dispersant Application Vessels in Alaska

<table>
<thead>
<tr>
<th>Payload</th>
<th>C-130/ADDS pack</th>
<th>Vessel</th>
<th>Helibucket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>5000 gallons</td>
<td>min. 1000 gallons</td>
<td>240 gallons</td>
</tr>
<tr>
<td>Max. Speed</td>
<td>150 knots</td>
<td>10 knots</td>
<td>54 knots</td>
</tr>
<tr>
<td>Min. Speed</td>
<td>130 knots</td>
<td>3 knots</td>
<td>27 knots</td>
</tr>
<tr>
<td>Max. Pump Rate</td>
<td>800 gallons/min.</td>
<td>12 gallons/min.</td>
<td>120 gallons/min.</td>
</tr>
<tr>
<td>Min. Pump Rate</td>
<td>100 gallons/min.</td>
<td>12 gallons/min.</td>
<td>79 gallons/min.</td>
</tr>
<tr>
<td>Swath Width</td>
<td>150-200 feet</td>
<td>90 feet</td>
<td>100 feet</td>
</tr>
<tr>
<td>Reposition Time</td>
<td>2 min.</td>
<td>0 min.</td>
<td>1 min.</td>
</tr>
</tbody>
</table>

a. These repositioning times assume 180° turns.

where the vessel-based system fully doses the slick in one pass. In any case, the turn-around time for a vessel is much less than the spray time, and therefore does not greatly affect the overall time the vessel remains on site, as would be the case for an aircraft-based operation.

In SL Ross (1997), oil-spill response scenarios (involving Alaska North Slope crude oil) were developed for three spill sizes (10,000 m³, 1000 m³ and 100 m³), two seasons, winter and summer, and two locations, one in Prince William Sound (PWS) and the other in the Gulf of Alaska (GOA). For simplicity, only the July scenario is considered in this paper.

A computer model was used to predict the behavior and properties of the hypothetical slicks (SL Ross 1997, Petro-Canada 1996). Table 5 was developed from the computer model runs. This shows key properties of the three selected spills just prior to the time a given application system first starts applying dispersant to the spill. The thicknesses and areas shown are typical for the spill sizes shown and are not peculiar to Alaska North slope crude oil spills.

Of particular importance are the slick thickness values in the table (the letter “x” represents the thickness of the thick portion of the spill). These may seem high, but, as stated earlier, the results of recent offshore experiments show that the thick part of spills, even small ones, can be relatively thick. For example, the thick part of a recent experimental spill involving 33 m³ of Alaska North Slope crude oil was estimated to be in the order of 1 mm even after 55 hours of spill exposure (Davies et al. 1998, Lewis et al. 1998). In Table 5, for the 100 m³ spill, the model predicts a thickness of 1.9 mm after 34 hours of exposure. Within the large error band
associated with both oil spill modeling and estimating slick thickness at sea, this comparison shows that the model is approximately valid.

It is assumed that the dispersant application systems available in Alaska, namely, the C-130 Hercules aircraft with ADDS packs, the helicopter spray buckets, and the vessels with spray equipment can be mobilized and ready to spray dispersant at site by 8 hours, 3 hours and 5 hours, respectively.
Table 5  Key Properties of Selected Oil Spills when Application Starts

<table>
<thead>
<tr>
<th>Spill Size, m³</th>
<th>3 hours (Helicopter response time)</th>
<th>5 hours (Vessel response time)</th>
<th>8 hours (C-130 response time)</th>
<th>Time for μ&gt;2000 cp</th>
<th>Thickness at 2000 cp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x, mm</td>
<td>Area, m²</td>
<td>x, mm</td>
<td>Area, m²</td>
<td>x, mm</td>
</tr>
<tr>
<td>10,000</td>
<td>12.6</td>
<td>685,000</td>
<td>11.1</td>
<td>760,000</td>
<td>9.8</td>
</tr>
<tr>
<td>1000</td>
<td>7.7</td>
<td>111,000</td>
<td>6.4</td>
<td>130,000</td>
<td>5.4</td>
</tr>
<tr>
<td>100</td>
<td>4.7</td>
<td>21,900</td>
<td>3.2</td>
<td>24,900</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Table 5 also shows the time taken for each spill to start to emulsify significantly and no longer be amenable to chemical dispersion (it is assumed conservatively (SL Ross 1997) that this happens for Corexit 9527 when the spill reaches a viscosity of 2000 cP). This is the so-called “time window” for dispersant use. So, the amount of time each dispersant application platform has for dispersant operation is the time window minus the above-noted mobilization times (3 hours, 5 hours, etc.).

From Table 5 the thickness of the thick portions of the spill during the time of dispersant operations ranges from about 6 mm to 13 mm for the 10,000 m³ spill, and from 2 mm to 5 mm for the 100 m³ spill. As stated earlier, these relatively high thicknesses present somewhat of a problem for the large aircraft. Because these craft are very fast, the dispersant dosage that they can supply to the slick is limited to a maximum of about 150 L/ha (for the C-130/ADDS system), which is equivalent to dosing about 0.3 mm of slick at a DOR of 1:20. This means, for example, that 20 passes in total are required to properly dose a 6-mm thick slick. The aircraft, then, ends up spending much more time turning around and re-positioning itself than actually spraying dispersant. Table 4 shows the repositioning times for the various platforms, as well as other specifications that were used in the response scenarios. It is seen for a given pass that the repositioning time for the large aircraft is about two minutes (180° turns), whereas the spraying time (not shown in the table) is only seconds. If one imagines that the spills in Table 5 have a uniform thickness of, say, 0.10 mm, the aircraft would spend much more of its time spraying (in a one-pass-only manner) and less time turning around and re-positioning. This would be a much more efficient spraying program, but, alas, it is a fiction: the oil is likely to be thick and require multiple dosing, as practiced by experienced responders in the U.K. (Lunel 1997).

3.3  Presentation of Modeling Results for Existing Systems

The results of the modeling exercise are presented in Table 6.
### Table 6. Dispersant Logistics for Three Spill Sizes, Three Platforms and Two Spill Locations in Alaska in July

<table>
<thead>
<tr>
<th>Spill Size m³</th>
<th>Platform</th>
<th>Mobilization incl. time to site, hrs</th>
<th>Time to apply 1 load at sea, hrs</th>
<th>Total time per sortie PWS hrs</th>
<th>GOA hrs</th>
<th>Time window vis.&gt;2000cP, hrs</th>
<th>Time window minus mobilization, time, hrs</th>
<th>Sorties possible per unit PWS</th>
<th>Total poss. dispers. applied, all units, m³</th>
<th>Oil dispersed 100% Effective m³ GOA</th>
<th>Oil dispersed 50% Effective m³ GOA</th>
<th>Oil dispersed 25% Effective m³ GOA</th>
</tr>
</thead>
<tbody>
<tr>
<td>10,000</td>
<td>C130</td>
<td>8</td>
<td>0.93</td>
<td>2.43</td>
<td>2.68</td>
<td>89</td>
<td>81</td>
<td>15.7</td>
<td>14.2</td>
<td>592</td>
<td>537</td>
<td>1000</td>
</tr>
<tr>
<td></td>
<td>helicopter</td>
<td>3</td>
<td>0.07</td>
<td>1.32</td>
<td>1.32</td>
<td>89</td>
<td>86</td>
<td>30.6</td>
<td>30.6</td>
<td>55</td>
<td>55</td>
<td>1100</td>
</tr>
<tr>
<td></td>
<td>vessel</td>
<td>5</td>
<td>1.4</td>
<td>5.65</td>
<td>5.65</td>
<td>89</td>
<td>84</td>
<td>7.0</td>
<td>7.0</td>
<td>79</td>
<td>79</td>
<td>1580</td>
</tr>
<tr>
<td>1000</td>
<td>C130</td>
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<td>27</td>
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Note: (a) The fraction of VFR and Daylight hours per day is 0.47 in July.
(b) The calculations assume that there are two C-130s available, two helicopter systems and three vessel-based systems.
(c) The payloads for the above three systems are 18.9 m³, 0.90 m³ and 3.78 m³ respectively.
(d) The C-130/ADDS pack uses only a portion of its load to completely dose the 100 m³ spill. The time of 1.45 hr is needed to treat the spill in one sortie.
The following is a list of assumptions that were made in the calculations:

- In July there are 18 hours of daylight per 24-hr period. VFR flying conditions are present for about 62 percent of the time. On average, then, 47 percent of the time each day is available for an aircraft-based response. This is also assumed for the vessel-based response, mostly because a small spotter aircraft is part of the operation.

- Two spill locations are chosen, one in Prince William Sound about 30 km (16 n. miles) south of Valdez, and the other in the Gulf of Alaska, about 75 km (40 n. miles) from Valdez and 30 km from Cordova.

- For the vessel-based response and the helicopter response, it is assumed that the staging area will be Valdez for the spill in Prince William Sound and Cordova for the offshore spill. All C-130 sorties are assumed to be based in Anchorage.

- It is assumed that dispersant is applied repeatedly to a section of slick until a dosage of 1:20 is reached; then the operation moves to a new area.

- Vessels are assumed to take about one hour to load an empty vessel with dispersant.

- The maximum dosage capability of the C-130 system is assumed, that is 130 L/ha (based on a dispersant pump rate of 800 gpm (0.050 m³/s), an aircraft speed of 130 kts (67 m/s) and a swath width of 180 ft (54.9 m).

To help understand the results in Table 6 it is useful to run through one example, say the 10,000 m³ spill considering the C-130 aircraft.

- This system is assumed to have a mobilization time of 8 hours, meaning it takes the system 8 hours to be loaded, fly to the site, and begin spraying for the first time, along with the necessary spotter aircraft overhead.

- The computer model indicates that once spraying begins, a period of 0.93 hours will be needed on site (spraying and positioning) per sortie.

- Once the aircraft’s load is spent the aircraft will take 1.75 hours (for the spill in the Gulf of Alaska) to fly back to Anchorage, be loaded, and to fly back to the spill location, ready to spray again.

- Once continuous operations are in place the total time per sortie is 2.68 hours (for the GOA spill). This is simply 0.93 hrs + 1.75 hrs.

- The time window for chemical dispersion is 89 hours, the time for this large spill to reach a viscosity of 2000 cP (see Table 5); so the operational time available for the aircraft is 89 hours minus the time required to mobilize (8 hours) or 81 hours.
• The fraction of time that daylight VFR flying conditions exist in the area is 0.47, so the number of sorties that each unit can make within the time window is (81 hrs/2.68 hrs per unit) x 0.47 = 14.2. (This is not rounded off for calculation purposes.)

• The payload of each system is 18.9 m$^3$ (Table 4; 5000 gallons = 18.9 m$^3$), and there are two C-130 systems, so the total dispersant that could be applied if necessary is 18.9 x 2 x 14.2 = 537 m$^3$.

• If the dispersant effectiveness at a dispersant-to-oil ratio of 1:20 is assumed to be 100% (on a fresh oil basis, not considering evaporation), the amount of oil that could be dispersed is 10,740 m$^3$. (Convert this to 10,000 m$^3$, the total spill size). If the dispersant effectiveness is taken to be 50% or 25%, the oil dispersed is 4050 m$^3$ and 2030 m$^3$, respectively.

All the spill scenarios in the Table 6 were calculated in a similar manner. In the "Oil Dispersed" columns (last three) where exact values of 1000 or 100 are shown, it means that there is an over-capacity of dispersant capability.

3.4 Discussion of Results

The example spill (10,000 m$^3$ = 63,000 barrels) occurring in July in the Gulf of Alaska shows that the two C-130 systems could disperse 100% of the original oil, if dispersant effectiveness for a dispersant-to-oil ratio of 1-to-20 is considered to be 100%. The value would be 54% if dispersant effectiveness is taken to be 50%, and 27% if only 25% dispersant effectiveness is assumed. In any case, each aircraft system is able to deliver and apply to the spill about 270 m$^3$ (1700 bbl or 71,000 gallons) of dispersant in the time available.

The results are much worse for the three vessel-based systems. Each vessel system was able to apply only 26 m$^3$ or about 10 percent of the amount each C-130 system could apply. The poor result is mostly due to the low payload of the vessel system, namely 1000 gallons (3.78 m$^3$). Because of this, each vessel is required to make 7 sorties in the time available. Much time is wasted because each trip back and forth to port to refill takes over 3 hours. Another, less crucial problem is that the dispersant pump rate is very low (12 gpm), so more time is spent on site in spraying than is necessary (1.4 hours). Both problems are easily corrected to yield good results, as described below.

It is clear that much better results might be expected with vessel-based systems if the need for them to return to base for resupply is minimized. The ideal situation would be for the vessel (or vessels) to have enough product on board to treat the entire spill, or at least to have enough product to complete a full day’s operation during daylight hours. If the capacity of the dispersant pump were 200 gpm (to fully treat 2-mm thick slicks) and operated for 12 hours at this rate, the amount of dispersant needed would be 144,000 gallons or 3400 barrels or 550 m$^3$. This would be enough dispersant to treat a 68,000 bbl (10,000 m$^3$) spill at a DOR of 1-to-20, assuming no inefficiencies. This is much dispersant (more than what is currently available in the State of Alaska), but not a great volume in terms of tankage for vessels. Supply ships and oil spill response vessels can often accommodate such volumes, either in their own holds or by the use of ancillary storage units.
Table 7 shows the results if an upgraded vessel-based system were used in the 10,000 m³ spill scenario that had the following specifications: a payload of 2000 barrels (84,000 gallons or 320 m³) and a dispersant pump rate of 200 gpm (760 L/min).

<table>
<thead>
<tr>
<th></th>
<th>C-130/ADDS</th>
<th>Old Vessel System</th>
<th>New Vessel System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobilization time, hrs</td>
<td>8</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Total time per sortie, hrs</td>
<td>2.7</td>
<td>5.7</td>
<td>15</td>
</tr>
<tr>
<td>Disp. <em>Time window</em>, hrs</td>
<td>81</td>
<td>84</td>
<td>81</td>
</tr>
<tr>
<td>Sorties possible per unit</td>
<td>14</td>
<td>7</td>
<td>2</td>
</tr>
<tr>
<td>Payload of platform, gal.</td>
<td>5000</td>
<td>1000</td>
<td>84,000</td>
</tr>
<tr>
<td>Number of units</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Disp. Pump Rate, gpm</td>
<td>800</td>
<td>12</td>
<td>200</td>
</tr>
<tr>
<td>Dispersant applied, gal.</td>
<td>70,000</td>
<td>7,000</td>
<td>168,000</td>
</tr>
<tr>
<td>Oil Dispersed, barrels</td>
<td>33,000</td>
<td>3,300</td>
<td>80,000</td>
</tr>
</tbody>
</table>

Simple calculations would show that this one system could easily treat the spill (at a DOR of 1-to-20) with two loads applied over two days. This would involve one return to port at nightfall of the first day to reload. The vessel would be loaded at night and would set sail in early morning of the next day, ready to start spraying at first light, with the help of the spotter aircraft. Assuming that the mobilization time for this system is 8 hours (the same as for the C-130), the *time window* for the spill, once dispersing starts at sea, is 84 hours (see Table 6), so there is a large cushion of time to accommodate inefficiencies associated with the operation, such as finding and moving from thick slick to thick slick, trial-and-error experimenting with dispersant flow-rates to accommodate changes in slick thickness, and extra mobilization time to load up the vessel.

Whatever the exact circumstances of the spill and the specifications of the response vessels, the above analysis shows that vessel-based dispersant operations make sense, and would be competitive with aircraft systems if the dispersant payload on the vessel is high and if the spill is not situated so far from the supply base that the time to reach the spill becomes excessive. What “excessive” means will depend on the speed and capacity of the vessel, the spill size, and, of course, the time window available for effective dispersing.
4.0 Vessel-based Dispersing versus Booming/Skimming

It is interesting to compare the use of vessels for dispersing and the use of vessels for a booming and recovery operation. The question is: which technique offers the most efficient use of the vessel and its storage capacity?

4.1 On-board Storage Requirements

Response to a marine oil spill using a vessel-based dispersing system would be similar in approach to a mechanical recovery system. In both cases the target would be the area of the spill that contains the most oil. In the former case, on-board or ancillary storage capacity must be available to contain the dispersant liquid, and in the latter case similar storage must be available to contain recovered oil. However, for a given amount of oil treated or recovered, the amount of tankage needed for dispersant is about 20 times less than that needed for recovered fluid, because effective dispersant-to-oil ratios are considered to be in the range of one-to-20. If water-in-oil emulsions are involved the tankage ratio would be even higher.

Environmental considerations aside, this suggests that current response vessels should be involved in dispersant operations to the extent that they are able and to the extent that the spill remains chemically dispersible. If such a vessel were to set aside some of its liquid storage space for containing dispersant and involve itself in a dispersant operation (say, up to the point where the oil was to become very emulsified and undispersible), much more of the spilled oil could be dealt with by the response vessel operating by itself without the assistance of ancillary vessels and storage units.

The practicalities of the above dual operation for response vessels need to be questioned, of course, but the main point is that much more oil can be dealt with by a vessel that is involved in oil dispersing than the same vessel involved in oil recovery, both vessels having the same tankage.

4.2 Treatment time versus recovery time

A spill recovery operation is a relatively slow process. This is mostly because of the slow speed that the system must use in moving through the spill (about 1 knot). For a vessel-based dispersing system the limitations are not as strict. Although swath sizes are less for existing dispersing systems compared to booming/recovery systems (about 30 metres vs. 150 metres) the vessel can travel at top speed in spraying the dispersant product onto the spill. This means that a vessel-based dispersing system can treat a spill of a given size up to two to three times faster than a vessel-based recovery system. This assumes that the pumping capacity of the skimming system is high enough to handle the oil encountered and that the dispersant pumping capacity is high enough to deliver the required amount of dispersant on the oil in one pass. Properly sized systems in both cases can handle the situation except in the cases of extremely thick oil slicks.

4.3 Summary

Response to an offshore spill with a vessel intending to recover spilled oil is basically the same as response with the same vessel intending to disperse the oil, except the dispersing operation can be faster by a factor of two or three or more, and the amount of spilled oil dealt with can be many times greater per unit storage volume on the vessel. The time to respond to and reach the spill is the same for each situation, assuming that the mobilization of the extra ships
needed in the recovery operation (for boom management) do not delay the response of the
recovery system.

This argument in favor of vessel-based dispersing loses validity, of course, in situations
where the spilled oil cannot be dispersed, either because it is too viscous or because dispersing
the spill is not recommended on environmental grounds.

5.0 Possible Design Improvements for Vessel-based Dispersing Systems
5.1 Conventional Systems

One of the most popular vessel-based dispersant application systems is \textit{Spillspray},
manufactured by Frank Ayles & Associates Ltd. As mentioned earlier, it is designed to treat
about 0.1 mm of slick at a DOR of 1-to-20. The system usually operates by educting dispersant
(at a flowrate of 5 to 15 gpm) into a larger flow of seawater (@ 60 gpm) and then spraying it
through 20 nozzles to achieve a reasonable spray pattern. The system can be converted to
spraying dispersant neat, but to achieve fan-shaped, overlapping sprays with the low dispersant
flow rate, the spray must be in the form a fine mist, and the fine particles in the mist are easily
carried away by the wind. The way the \textit{Spillspray} system gets around this is to educt the
dispersant flow into a much larger water flow before spraying the slick. The problem with this,
however, is that using relatively large drops of water to carry dispersant chemicals to thin slicks
of oil is a poor way of ensuring good dispersant/oil mixing. Unfortunately, there is no effective
alternative when trying to treat thin slicks, such as those in the 0.1 mm range.

The solution is not to attempt to spray thin slicks, but to concentrate on the thick portions
of the spill, as mentioned repeatedly in the earlier part of the paper. This would mean forgetting
the use of water to carry the dispersant to the oil slick and simply spraying neat dispersant using a
large capacity pump, such as the 60 gpm one used in the \textit{Spillspray} system, or better yet a larger
one.

There are other problems with conventional spray-boom systems that are not as easily
corrected. A common complaint is that the booms are cumbersome to install and do not work
well in rough sea conditions where the roll of the ship can alter the relative angle between the
boom and the water surface and dramatically affect spray patterns and dispersant coverage. To
avoid submerging the spray booms in rough seas, and possibly damaging them, the length of the
arms is usually limited to 10 metres or 30 feet each. The other limitation relates to the allowable
speed of the vessel. To avoid having the bow wave wash out the dispersant before it reaches the
oil-water interface, the vessel’s speed must be kept to less than 8 to 10 knots.

5.2 Consideration of a Fire-Monitor System

There have been several innovations over the years which have served to eliminate these
two limitations, thereby improving the performance of vessels in dispersant application. One
novel method relies on technology developed for agricultural spraying purposes, and adapted for
dispersant application (Allen 1985, Barbouteau et al. 1987). One problem with the system is that
the spray distribution is much less uniform than the conventional spray boom method. Other
approaches, which mostly address the slow-speed problem of vessels, have included the use
hovercraft (D.F. Dickins et al. 1987) and hydrofoil systems (Vacca-Torelli et al. 1987). The
obvious problem with these ideas is that such vessels are expensive and largely unavailable.
One of the best ideas to emerge recently is to use a fire-monitor system. A fire monitor is essentially the swivelling device that connects the fire hose or piping to the spray nozzle. It has been shown that commercially available fire-monitor systems can be modified and used effectively to apply dispersant to slicks if proper nozzles, pressures, flow rates, dispersant metering and vessel operation practices are adhered to (Marucci et al. 1991, Major 1993, Major et al. 1995, Major and Chen 1995, and Lunel et al. 1995). The modification relies on placing a mesh screen over the fire nozzle to scatter the droplets evenly. Generally, the use of fire monitors to spray dispersant can double the range of application, and allow the vessel to travel at faster rates. Monitors can provide up to 20 metres (65 feet) of spray swath, while still maintaining uniform drop sizes and drop distribution. The swath can be doubled by having a monitor on each side of the vessel. Fire monitors have the advantage of being low-cost, rugged and easily installed and operated.

The following are some preliminary ideas of the requirements for implementing such a system. The primary elements to consider are: (1) the dispersant pump, (2) the spray nozzle, and (3) the fire monitor.

**The Pump.** Some offshore work boats are equipped with 100 to 300 gpm fire monitors. At a dispersant pump rate of 100 gpm, an associated spray swath of 65 feet, and a vessel speed of 10 knots, one monitor would be able to dose a 1.3 mm thick slick at a DOR of 1-to-20. For lower vessel speed and lower application rates a smaller pump would be feasible. There are a number of commercially available pumps that would be suitable for this application. These are self-contained engine-powered units that could be placed on the deck of a vessel and used to feed the fire monitor system.

**Spray Nozzles.** Tests completed by Marucci et al. (1991) revealed that standard adjustable fire-fighting nozzles do not create a uniform distribution of water over the swath extending from the nozzle location to the full reach of the spray. Their work identified that a straight stream nozzle fitted with a ¼ inch screen mesh bag generates a uniform spray coverage and appropriate drop sizes when operated at a pressure of 100 psi at the nozzle. Dispersant effectiveness tests completed by Major (1993) and Lunel et al. (1995) have shown that the drop sizes and spray patterns created by fire nozzles of this type results in an effective application of dispersants.

**Fire Monitors.** In this application it would be desirable to have a portable system that could be placed on a vessel of opportunity with minimal set-up time or vessel modifications. Portable monitors made of aluminum alloy are commercially available, but none, it seems, are available in a stainless steel or brass construction. However, brass monitors in a permanent deck mount configuration do exist, and a mounting frame could be easily constructed so that they could be used in a vessel-of-opportunity type of application.

6.0 **Conclusions and Recommendations**

It is concluded that vessel-based systems are suitable for use in applying dispersant on offshore oil spills. Vessel-based systems have the advantage over aircraft systems in terms of their cost and availability, their better spray control and accuracy, and their ability to dose thick slicks in one pass. The advantage is lost, however, if the dispersant payload on the vessel is relatively small and the spill is located very far from the base of operations. This is because the time required to shuttle back and forth between the spill and the operations base would be too
long relative to the time window that is usually available for effective chemical dispersion. The fact is, however, that marine spills tend to occur in restricted water near ports where vessels having suitable tankage are usually located and where dispersant stockpiles could be stored ready for use.

Some research is required to (1) design, assemble and test a vessel-based, fire-monitor system for applying chemical dispersant onto marine oil spills, and (2) to provide plans for the establishment, activation and use of such systems in specific areas and spill situations.

7.0 References


Mackay, D., I.A. Buist, R. Mascarenhas and S. Paterson, Oil Spill Processes and Model, Department of Chemical Engineering, University of Toronto, Toronto, Environmental Protection Service Publication No. EE-8, 1980.


