Computation of Resource(s) and Type(s)

for

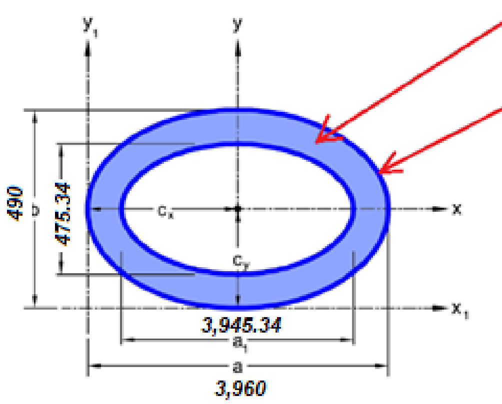
Rx Holding & Active Suppression

through

Fire Thermal Intensity Estimation

What follows in the pages below is the determination of resources required at a minimum to engage in suppression of a fire that is 35 acres in size, burning in 10mph winds with a 5% slope in Fuel Model 3. Comprised with this model was a fuel Model 7, however, due to the nature of the fuel type and rate of spread, that fuel type's Rate of Spread was significantly slower than the Fuel Model 3 and was thus omitted by reason that it would have become an interior pocket.

The shape of the fire is that of an ellipse, then, after the heel & interior are consumed it will most likely become similar to that of a half-hollow ellipse (shown below), with an active fire perimeter as shown in Blue. The reality is that the fire will be closer to a parabola in shape (on page 3) with the heel nearly out along with diminished flanks. We use the ellipse to attempt to show "active width" for the Rate of Spread figure of 7.33ft, hence, the blue line at the head would be the active width of the Rate of Spread estimation.



Area

$$A \dots\dots = \frac{\pi}{4}(ab - a_1 b_1)$$

Perimeter

$$P \dots\dots = \pi\left(3\left(\frac{a}{2}+\frac{b}{2}\right) - \sqrt{\left(\frac{3a}{2}+\frac{b}{2}\right)\left(\frac{a}{2}+\frac{3b}{2}\right)}\right)$$

$a = 3960,\quad a1 = 3945.34$

$b = 490,\quad b1 = 475.34$

$$a - a1 = 3960 - 3945.34 = 14.66ft \qquad \frac{14.66}{2} = 7.33ft$$

The ellipse shape for those that don't know is the common shape most fires take on. Richard Rothermel in 1972 in his research paper INT-115 expressed this in his preface. In Rothermel's Abstract, he states: *The model is complete in the sense that no prior knowledge of a fuels burning characteristics is required. All that is necessary are inputs describing the physical and chemical makeup and the environmental conditions in which it is expected to burn*.

This means that YOU the engine captain or crew supervisor can use the Nomograms and be just as accurate as the scientist or engineer for predicting fire behavior using these tools, provided you select the correct fuel model nomogram.

Rothermel shows you how much heat in Btu a fire is generating, and WAE simply shows you how to use his numbers to determine how much cooling (water) that same model needs for suppression. The problems of water supply, water delivery, water tenders required, engines required, aircraft required, etc. etc. are to be worked out by you, or someone that has a very keen sense of fire ground hydraulics know-how and timing because this is all timing-based. Contract water tenders, that have PTO pumps, that are not NFPA-rated will nearly never meet the flow demands and pressures your operation will require. If each of the ground resources is acting independently, as well as the air resources (if present), then there will always be deficiencies in the holding or suppression efforts. This problem is solved by communication and coordination between the water supply officer and air resources using the water.

If you want to learn how to read Nomograms, I suggest you download Faith's work at this link.

https://www.frames.gov/documents/behaveplus/publications/Heinsch_2019_Nomograms_7Steps.pdf

Teaching folks how to read Nomograms is not the point of this writing. And teaching folks how to read the right carrier fuel is NOT either.

This whole thermodynamic issue is what makes up the FireBridge. That means Bridging Fire Planning to Fire Operations. 3 main parts comprise this process for better success and understanding.

- Determine the Proper Fire Behavior Nomogram and fire outputs from that nomogram such as the Heat Per unit Area, and Rate of Spread and Intensity in Btu per second and square foot.
- Determining the Thermal Capacity of water for the altitude the fire is located.
- Determining the Amount of water necessary can then be used to determine the right resource type as well as the number of resources or even the nozzle type(s).

A sub-section of the above 3 elements involves knowing Fire Ground Hydraulics well enough that once you have a number for the amount of water required, you then understand and know how to calculate the right number of water tenders & type as well as the right number of engines & type. This commands that whoever is making this determination, that this individual, understands the difference between fire ground and pump hydraulics and that such a person knows the pump capabilities of other apparatus. Ideally, such a person should have a 3-ring binder of the most likely Pump curves they work with kept in their apparatus.

RX or Suppression:

The first order of business is the initial estimation of the expected fire intensity based on fuel type, fuel moisture (live and dead), slope %, and winds. Again, these are the Inputs Rothermel spoke of, and this is shown on page 4 in the form of a Fuel Model 5 Nomogram. However, an important point with this is that the models assume a Steady State. There is no slowing or accelerating predictions with the models and it is assumed to be continuous. The nomograms do allow you to lay a plot over the existing Dead fuel moisture and HPA and estimate different wind speeds to obtain different ROS and Intensity outputs on the same model.

On the next page, you will see the following Lines and colors.

Red Line is the 3mph plot, which, is the primary plot. ----------

Orange line for the 5mph plot. --------

The blue line is the dead fuel moisture percentage line. ---------

The green line in the upper left quadrant is the K-line ----------

This K line is for your live fuel moisture and this line acts as a turn line. At a point when performing the plot, you will draw a line up to that line and make a right turn. That is its function. Hence this is a limit line for this quadrant.

Green Circles are the intensity locations for the respective plots. We have 6% dead fuel moisture and we decide on 110% live fuel moisture. Our slope is 30% and the effective mid-flame wind speed gives us 3mph we added 5mph to show what that would do should we have a sustained wind over the 3mph to determine what the ROS and Intensity would be alongside the initial 3mph lot. The outputs are in RED at the top of the fuel model. The inputs are in Blue at the Top of the Fuel Model.

This fuel model will use the same 700ft altitude and a Thermal Capacity figure of 1,134Btu/pound as the Fuel Model 3 that will be shown later on.

The fastest ROS on this plot below shows us that it is traveling at .33 feet per second. To give you a perspective that is .33' x 12" = 3.9" inches each second or 19.8 feet per minute. We can also tell that the flame length on the 3mph estimate is about 3.5 feet. And for the 5mph plot jumps to 4.75 feet approx. This can be held and now we'll dive into determining what can hold it.

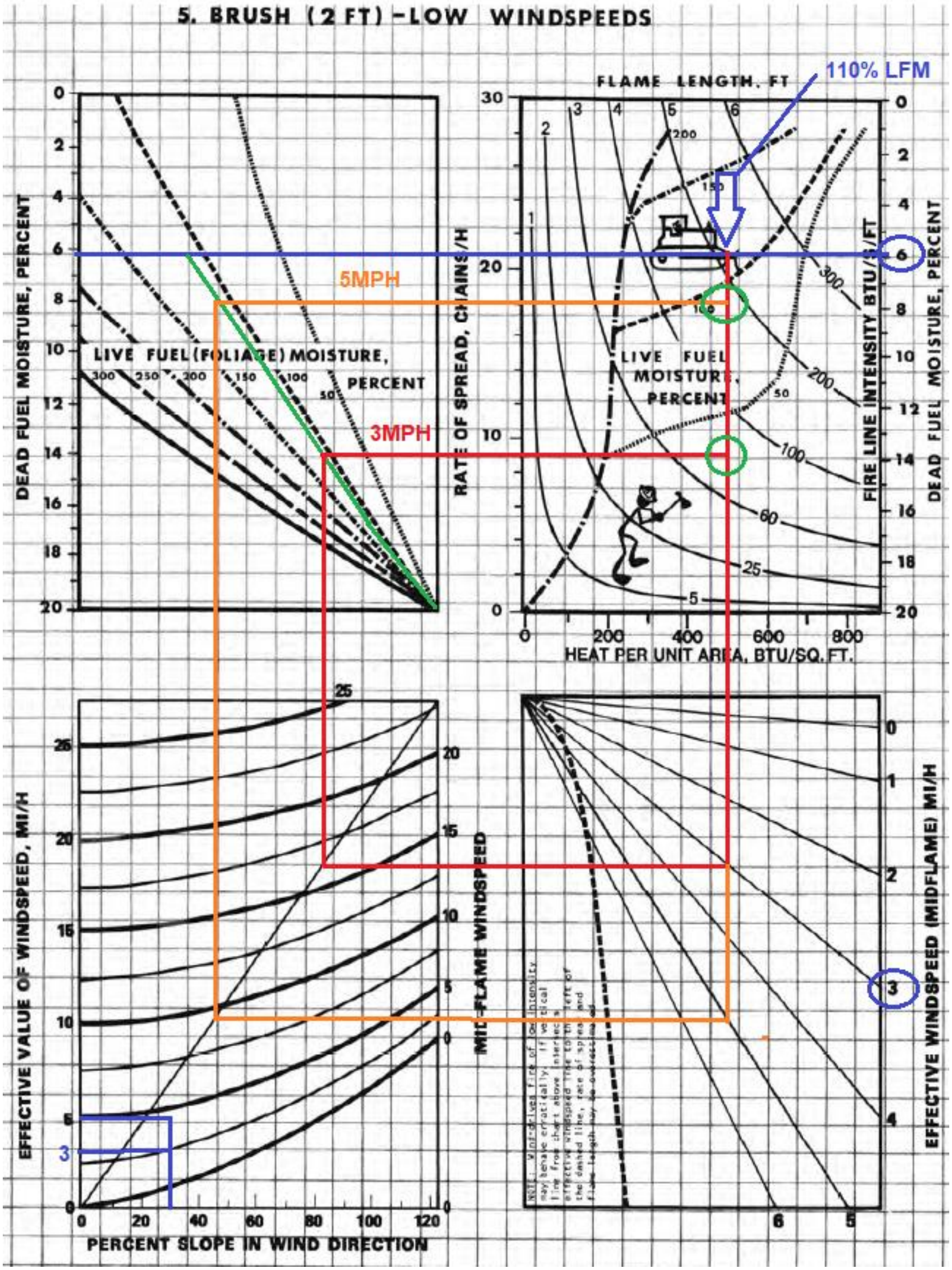
Blue Text is used for the input variables

Red Texts are used for the OUTPUT factors. This set is what you are making your decisions on.

One can take any nomogram of their expected carrier fuel, print them out, and make 3 plots using the same fuel moisture to obtain a visual of what each intensity will be with a corresponding ROS figure as shown on the next page. Here, a simple 2mph increase in wind shows up with double the ROS and nearly double the intensity!

6% Dead Fuel Moisture
110% Live Fuel Moisture
30% SLOPE & 3MPH & 5MPH

3MPH output = 9Ch/hr = .165ft/sec HPA = 500 Btu/s/ft = 82.5, FL 3.5ft
5MPH output = 18Ch/hr = .33ft/sec HPA = 500 Btu/s/ft = 165, FL 4.75ft
20GPM = .33gal/sec, x 8.34 = 2.7lbs/sec x 1134 = 3,149Btu/sec
3,149 / 165 = 19 ft per sec 1 nozzle can handle alone.



For the Fuel Model 5, on page 4, here are the Outputs.

.165’ feet x 12” = 1.98 Inches/sec

3mph – 9Ch/hr, = .165 feet per sec ROS. HPA = 500 Btuft^2, Intensity = 82.5Btu/s/ft

.33’ feet x 12” = 3.96 inches/sec

5mph – 18Ch/hr, = .33 feet per sec ROS. HPA = 500 Btuft^2, Intensity = 165 Btu/s/ft

Using the same figures for the parabolic fire line from page 8, the arc length of the burn is 7,967 feet. From this point determining resources could take on any number of approaches, however, it would be best if such an approach was based solely upon the thermodynamic principles of the arc line of the fire. The fire is generating 657,312.53 Btu every second along the entirety of the fire line. If you divide the Btu figure by the line length, you will see that it matches the figure estimated by the nomogram of 82.5 Btu/s/ft.

Let us now determine how much heat a type 6 booster line can cover in square feet.

For 20 GPM (rated flow), this nozzle can absorb the following:

20gals/min x 8.34lbs/gal = 166.8lbs/min. 166.8lbs x 1,134 btu/lb = 189,151 btu/min. To determine the btu per second rate we divide 189,151/60 and obtain 3,152 btu/sec.

Next, we determine how many square feet a single nozzle can “Cover” at the same rate the fire is generating its intensity.

3,152.5 Btu/sec ÷ 82.5 Btu/sec = 38.2 square feet. Is that all? NOT REALLY, most at this point would naturally assume their engine would be limited to this fuel model and ROS to just 38 feet of line. Keep in mind the ROS is .165 feet or 1.98 inches every second. This is the active flame width.

To Determine the Equivalent line length or distance we can cover for the 38 square feet, take the 38 feet of area, and divide by the ROS of .165 ft/sec. The result of 230.3 feet is the distance a single 20gpm nozzle should be able to cover. Providing this fire maintains its “steady state”, we should be able to cover a 230-foot section of line with no issues. At this point, we need to consider a couple of factors.

1st. how long will it take in seconds, at the current rate, for a fire to burn a solid 1 foot in advance at this rate? And how far can you travel (walk) at the same rate?

2nd. Is there enough time in seconds to cover a sizeable distance without the worry of our fire flanking us?

To verify #1. 12 inches ÷ .165 ft/sec = 72.7 seconds for the fire to travel one foot. What about you? If you’re walking at a stride of 3 feet per second (2mph) for 72.7 seconds how many feet will you have covered? 72.7 x 3 = 218 feet of forward distance. For the same time frame, the fire is not able to travel fast enough to flank you. Thus far holding does not appear to be a problem at this time from the mathematical point.

To determine #2, the time it would take for the fire to "advance" or flank us with the same 38 feet. Use the same formula from the previous page, yet with different parameters assigned to it. We calculate that to travel 38 feet at .165 feet per second will take 38ft ÷.165ft/sec = 230 seconds, (3.8min). And 230 seconds x 3ft/sec we should cover 690 feet across the ground. Ideally in 460 seconds (460/60=7.6 minutes) one should be able to cover 1/8th of a mile worth. A single-engine could cover a ¼ mile in 15.2 minutes. And half a mile in 30.4 minutes.

Up to this point, you know that in 1 min 12sec (72 seconds), each Type 6 engine can have a Fire Fighter walk 218 feet to cover the 38 equivalent square feet and cover the Heat absorption capacity required of the nozzle for the fuel model 5. You now know your nozzle can absorb 38 times the amount of heat the fire is putting out. This is a major safety factor to take advantage of. The major caveat to consider is the terrain that one is trying to move across, can you move at the rate the math is saying you need to? Oftentimes, NO. However, this is calculated this way to show that you can at least gauge to a better degree what each engine, firefighter, nozzle, aircraft, piece of equipment, etc. is capable of handling for a more accurate figure on holding estimates. It will never be perfect or spot on, but your goal should be to try to be as accurate as possible. And you never will be unless you make a study of fire ground thermos dynamics.

A theoretical formula for calculating extinguish time is Time ≅ Btu/gen(min or sec) ÷ Btu/absorbed(min or sec). For this fire, we have 657,306.51/3152.5 = 208 seconds. The formula is not always practical and requires the right conditions to be usable.

The problem with the time computed is that to cover the 7,967-foot distance in 208 seconds means that the ground speed would have to be 26mph, 22kts, or 38 feet per second. Since no person alive can walk 38 feet in one second, this means 1 of 3 things need to happen. 1. Add more resources. 2. Allow the calculated area to burn over the given time with just one engine on the scene. 3. Initiate the use of aircraft that can cover a greater distance for a given second. As you know, we added more resources as described above. For argument's sake, a Type 3 Helicopter at 80kts = 135ft/sec.

The 5MPH Plot

We also have our .33 ft/sec or 5mph plot. Looking at this, .33 x 500 = 165btu/s/ft x 7967 = 1,314,555Btu/sec. of line intensity. This is double the previous and while the booster nozzle could handle this as it is 19 times the Btu capacity of the fire it will require slightly more time in the same location than the previous plot and thus will require more water. All other factors already determined would remain the same.

On the next page, we look at the 35-acre FM3 fire and its plots.

Fuel Model 3.

Elliptical Formulas, Area, and Perimeter approximation dimensions in feet for 35 acres of wind-driven fire. 10mph, 5% slope. FDFM 3%. No live Moisture.

HPA –Heat Per unit Area, Btu^{ft2} , **ROS** – Rate of Spread - ft_{sec}

$Circumference, or\ perimeter$

$a = major\ axis, half\ distance$

$b = minor\ axis, half\ distance$

$$C \approx \pi(a+b)\left(3\frac{(a-b)^2}{(a+b)^2\left(\sqrt{-3\frac{(a-b)^2}{(a+b)^2}+4}+10\right)}+1\right)$$

$$C \approx \pi(1980+245.09)\left(3\frac{(1980-245.09)^2}{(1980+245.09)^2\left(\sqrt{-3\frac{(1980-245.09)^2}{(1980+245.09)^2}+4}+10\right)}+1\right)$$

$$C = 8{,}101.33526\ ft$$

Area of an ellipse

$a = major\ axis$

$b = minor\ axis$

$$Total\ Ellipse\ Area = \ \pi\ ab$$

$$A = 3.141\ (1980 * 245.09) = 1{,}524{,}602.4ft^2$$

35 acres x 43,560 = 1,524,600

$$Perimeter\ Area = \frac{\pi}{4}(ab - a1b1) = 51{,}068ft^2$$

$$Intensity\ of\ perimeter\ Btu/sec = 8{,}101\ x\ 6{,}230 = 50{,}469{,}230$$

This figure assumes a 7.3ft thick perimeter line times the perimeter length itself. However, when estimating intensity with any type of wind component, you normally can dismiss the heel as the fire is progressing forward. If something arises where holding becomes necessary, that suppression mode begins on the outer edges shown in the ellipse profile shown earlier.

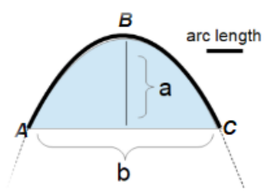
If we divide the area and intensity in half and re-calculate for a more parabolic formation, then the following is produced. On page 4, the same shape is calculated for the full 35 acres, showing what the dimensions of the fire shape would have to be to generate nearly the exact figures as the elliptical perimeter.

Parabolic Fire Area & Acreage Intensity Estimation

Points	A	Lengths	a	1980	user
	B		b	490	user
	C				

Arc Length	ABC	4,020.27	ft

$$L = \frac{1}{2}\sqrt{b^2 + 16 \cdot a^2} + \frac{b^2}{8 \cdot a}\ln\left(\frac{4 \cdot a + \sqrt{b^2 + 16 \cdot a^2}}{b}\right)$$



Parabola Area ft^2	ABCA	646,800.00	
Parabola Acreage	ABCA	14.85	

$$Area, A = \frac{2}{3}\, x\, ab$$

Arc Length x ROS	Area/sec	29,468.60	Ft^2	Aircraft Load Cap	1300	Gals	user
	ROS ft/sec	7.33	user	Number Aircraft	2.04		
	HPA	850	user				
Arc Intenstiy		25,048,311.41	Btu/s/ft				

Water *ThCap*	1134.00	Btu/lb	user
Gal/s/req'd	2,648.50		

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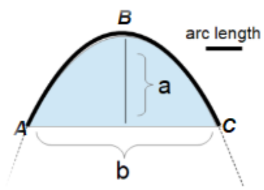
Below, we can see the ¾ mile arc length for axis *a*, of 3,960 feet. And the width would have to be 577.5 feet to equal an area of 35 acres. Also shown are the equations used to determine the area and actual arc length of ABCA. That is 7,967.42 feet when the elliptical formulas produced a perimeter length of 8101. Both are correct when one considers the dimensions for the total acreage. The width had to be increased by 87ft to obtain the 35-acre plan.

Parabolic Fire Area & Acreage Intensity Estimation

Points	A	Lengths	a	3960 user
	B		b	577.5 user
	C			

Arc Length	**ABC**	**7,967.42** ft

$$L = \frac{1}{2}\sqrt{b^2 + 16 \cdot a^2} + \frac{b^2}{8 \cdot a}\ln\left(\frac{4 \cdot a + \sqrt{b^2 + 16 \cdot a^2}}{b}\right)$$



Parabola Area ft^2	**ABCA**	**1,524,600.00**
Parabola Acreage	**ABCA**	**35.00**

$$Area, A = \frac{2}{3}\,x\,ab$$

Arc Length x ROS	Area/sec	58,401.22 **Ft^2**	
	ROS ft/sec	**7.33**	user
	HPA	**850**	user
Arc Intenstiy		**49,641,039.06 Btu/s/ft**	
	Water *ThCap*	**1134.00 Btu/lb**	user
	Gal/s/req'd	**5,248.82**	

Aircraft Load Cap	**1300 Gals**	user
Number Aircraft	**4.04**	

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Also note that the gallons per second required is nearly the same amount, only 48 gallons less. The key point that one should understand for rough estimation for any holding functions is the actual shape and formulas used here may be considered unnecessary, even during active suppression. The critical element first and foremost is using the right nomogram for the proper carrier fuel and the most up-to-date fuel moistures as close to the burn day as possible. In other words, don't use Fuel Moistures that are a week old and think "we're good"! You'd be surprised, it's happened. When planning a burn, I would consult with your people who make a specialty of moving water. I would recommend that you use a whole percentage point less than what the driest fuels are measured at. This produces a slightly higher HPA, however, over-estimating on this side of the scale will often mean you have a better chance at suppression should something go wrong. When your nomogram is complete and you have the HPA, the ROS & the Intensity figures, and other outputs as shown on page 9, you may then simply take the fire line length, multiply this by the ROS figure, then simply multiply that by the HPA figure to obtain the fire line intensity regardless of shape.

It will not be 100% accurate but you'll be in the 90th percentile because actual fire lines tend to change on the ground. Remember, we're studying fire ground thermodynamics. This is not taught in wildland suppression courses.

The above parabolic images are overkill and completely unnecessary for average *boots-on-the-ground* folks who simply need to determine resources. However, the caveat to this is to also not be so quick to dismiss such information either. The profile shapes and formulas are shown so that one making a study of fire ground heat generation, understands the elements that were used in its determination so they'll have a better understanding of how to COOL the arc length or active line. People learn faster with visual aids, so this is just that.

The most common thing that many begin to do is compute the entire area and determine cooling requirements based on that total area. This is NOT what I would recommend. Since the Fire Behavior Nomograms were designed to determine "*fire line*" intensity, stick with that. The Nomogram will tell you what your projected "*Active Width*" of that *fire line* will be in feet if you remember to convert the chains per hour to feet per second. This is covered in the FireBridge paper but we will go over it here briefly.

Looking at the included nomogram for this fire, you can see the Rate of Spread is in chains per hour and is 400. For the average engine operator or captain to use this information successfully one has to convert to feet per hour first, so multiply the 400ch/hr by 66 to obtain 26,400 feet per hour. Next, divide the feet/hr figure by 3,600 to obtain the feet per second, 7.33. *{Here is what is happening when you divide by 3,600. When you have 26,400 feet/hr and you divide just by 60, you will arrive at 440, which, is the figure in feet per minute. Dividing by 60 again takes that 440 and converts to feet per second, and you arrive at 7.33. the 60 x 60 = 3600, so dividing by 3,600 saves a middle step}.*

There is a shortcut that you can use to save a calculation step. 26,400 chains/hour multiplied by .01833 will give you the same result in feet per second. 26,400 x .01833 = 7.33. Any chain/hr number multiplied by .01833 will yield the ft/sec number. Just make sure you maintain the 5 digits to the right of the decimal to have the proper accuracy.

The nomogram ROS figure is what I call the active width and is the only element I am concerned with when calculating the required heat absorption or cooling aspects even though there may still be open flame inside that interior. However, most who have been in fire long enough would know that 90% of the time, we do not concern ourselves with "interior" smoke or open flame unless there is a reason to. The same applies here.

Cooling the Fire:

Required Cooling (*used interchangeably with heat absorption*) demand of the fire front can only be known once the intensity is known (estimated) as shown below.

$$Intensity\ \ Btu/sec\ /ft = 7{,}967'^{ArcLength}\ x\ 6{,}230^{\frac{Btu}{S}/ft} = 49{,}634{,}410$$

This means for this 7.33ft x 7,967 ft parabolic front, 49+ million Btu is being generated every second. We are not concerned with the interior, just the edge. We also said that in the real world, the heels and flanks tend to be less active and intense in wind-driven conditions.

"Thought Process"

We need to apply an amount of Either Water to cool the fire at an absorption rate equal to or greater than the Generated Intensity, OR, we need to remove an amount of Fuel that equals approximately the same amount of Btu, OR, a combination of BOTH. That is, half the Btu in water for heat absorption and half the amount of Btu in fuel removed that when added together will then equal the total thermal capacity of what the fire is generating or projected to generate. This fuel removal is often done either by shot crews, or dozers, feller bunchers, etc. The point is that one probably should remove at a minimum what the active width ROS is calculated to be based on the nomogram. And remember, if there are any unexpected increases in winds, that will have an increase on your ROS, and hence your active width will go up. Instead of a 1ft fire line width, you could be looking at 3 ft and it will be for every second.

Calculating Water:

The next step is for one to have computed the boiling temperature of water for the altitude that the fire is located at, and compute the total thermal capacity of each pound of water. Doing this first, means you do not have to keep repeating this portion of the math each time you need to re-calculate water delivery demands because once computed, it is very unlikely the water temperature and altitude will be changing on you to affect your outcome. (See Heat Capacity of Water worksheet at the end of the document). Trick, the figure 1,123 is the btu/lb of water for 5,000ft msl and 50 deg f.

For this fire, the altitude was stated to be at 700'msl. Let us compute the boiling temperature for this altitude and then compute the Thermal Capacity of a pound & gallon of water.

1st Obtain the altitude factor: $\frac{700^{msl}}{1{,}000} = .7$

2nd. Multiply this altitude factor by the thermal Lapse Rate of 1.84°, $.7\ x\ 1.84° = 1.288°$

3rd. Subtract the result of 1.288 from the Sea level boiling temperature of 212° to obtain the new boiling temperature for the altitude of 700 ft. $212 - 1.288 = 210.7°$

4th. Determine the Specific Heat Capacity, *Sh*, of a pound of water by obtaining the temperature of the water to be used and subtracting this temperature from the new boiling temperature.

We'll say the temperature is 47 degrees. $210.7 - 47 = 163.7$. This is the amount of heat in Btu that each pound of water will absorb in raising the temperature from 47 degrees to 210 degrees for this altitude and is called the Specific Heat, Sh.

5th. Water will absorb another 970.3 Btu per pound in heat from boiling to the conversion of steam without an additional rise in heat. Adding the Latent Heat of 970.3 to the Specific heat Capacity of 163.7 determines the Thermal Capacity per pound of water. 163.7 + 970.3 = 1,134. Now multiply the Thermal Capacity by 8.34 to obtain the total heat capacity for each gallon. $1{,}143\ x\ 8.34 = 9{,}457.5$. For a SEAT holding 800 gallons of water, this allows 7,566,000 Btu of heat absorption (cooling) capacity. For a 20gpm engine nozzle, it means 189,150 Btu/min, and for 60gpm, this equates to 60 x 9457.5= 567,450 Btu/min

6th . Convert any gpm Btu figures to Btu per second by dividing the Btu/min figures by 60. 20 gpm Btu is 189,150, thus 189,150/60 =3,152 Btu/sec, and 567,450/60 = 9,457.5 Btu/sec. Keep in mind that 60 gpm is 1 gallon per second and 20 gpm is .33 or 1/3rd gallons per second. Do Not forget this!

Computing the amount of water needed for the fire.

Looking at the parabolic fire arc, we have a pretty good estimate of what the fire is generating in Btu, and how much heat, the water we have to work with can absorb on a per pound and per gallon basis. We can now determine how many gallons this fire will take, and if such will exceed the amount of water a particular nozzle or aircraft can either deliver or carry, which, 90% of the time, it always will. We can then use this information to perform a simple division problem to determine both the number of gallons and the number of aircraft. Or if the ROS is low enough, how many engines or nozzles, etc.

The fire's active width from the image on page 4, is generating 49,640,584.33 Btu every second (*this number is slightly different due to Excel's precision vs a standard calculator*). From the thermal capacity of water arithmetic we performed, we can determine the amount of water we need in pounds by dividing the Fire Intensity figure by the thermal capacity figure as shown below.

$$lbs\ water = \frac{49{,}640{,}584^{btusec}}{1{,}134^{thcap}} = 43{,}774.7^{lbssec}$$

Next, divide the lbs/sec figure by 8.34 *lbs* to obtain the gallons required.

$$gallons\ req'd = \frac{43{,}774.7\hat{}lbssec}{8.34^{lbsgal}} = 5{,}300.2^{galssec}$$

Three (3) things to keep in mind at this point 1.) This needs to be delivered every second for the entirety of the calculated line edge ONLY. 2.) The entire line, or perimeter, may or may not be practical or achievable with current resources on hand, and 3.) The line can be further divided or broken down into manageable numbers based on the field areas or asset priorities. That is prioritized for specific target areas of the fire.

Next: Determine the number of loads based upon a simple division problem. The amount of water needed is divided by the carrying capacity of the aircraft to be used.

For a SEAT, at 800 gallons, it's simply 5,300 / 800 = 6.63 so round up to 7 aircraft. The aircraft should be making sequential drops to be effective. Your goal is to create an aerial nozzle as much as possible rather than single load and returns that diminish effectiveness due to the Btu vs Time vs Load Capacity curves. If an S64 helicopter is being used, then 5,300/2000(rounded down) = 2.6, rounded to 3 are now needed. And for Type 3 helicopters with say a 180-gallon bucket, 5300/180 = 29 are needed.

On the next page is the Fuel Model 3 Nomogram. We always hear of fuel moisture. Pay particular attention to the Fuel moisture (3%), then, follow the red line vertically down where it passes the HPA, Heat Per Unit Area. Notice that No other factor affects BTU than the fuel type and fuel moisture. Period!

Fire Intensity comes into the mix from the slope % and the mid-flame wind speed. This secondary factor controls the Rate of Spread in Feet per Second, but it is always stated in Chains. Always think in feet per second, and this makes it a lot easier to understand what needs to be done on the fire ground.

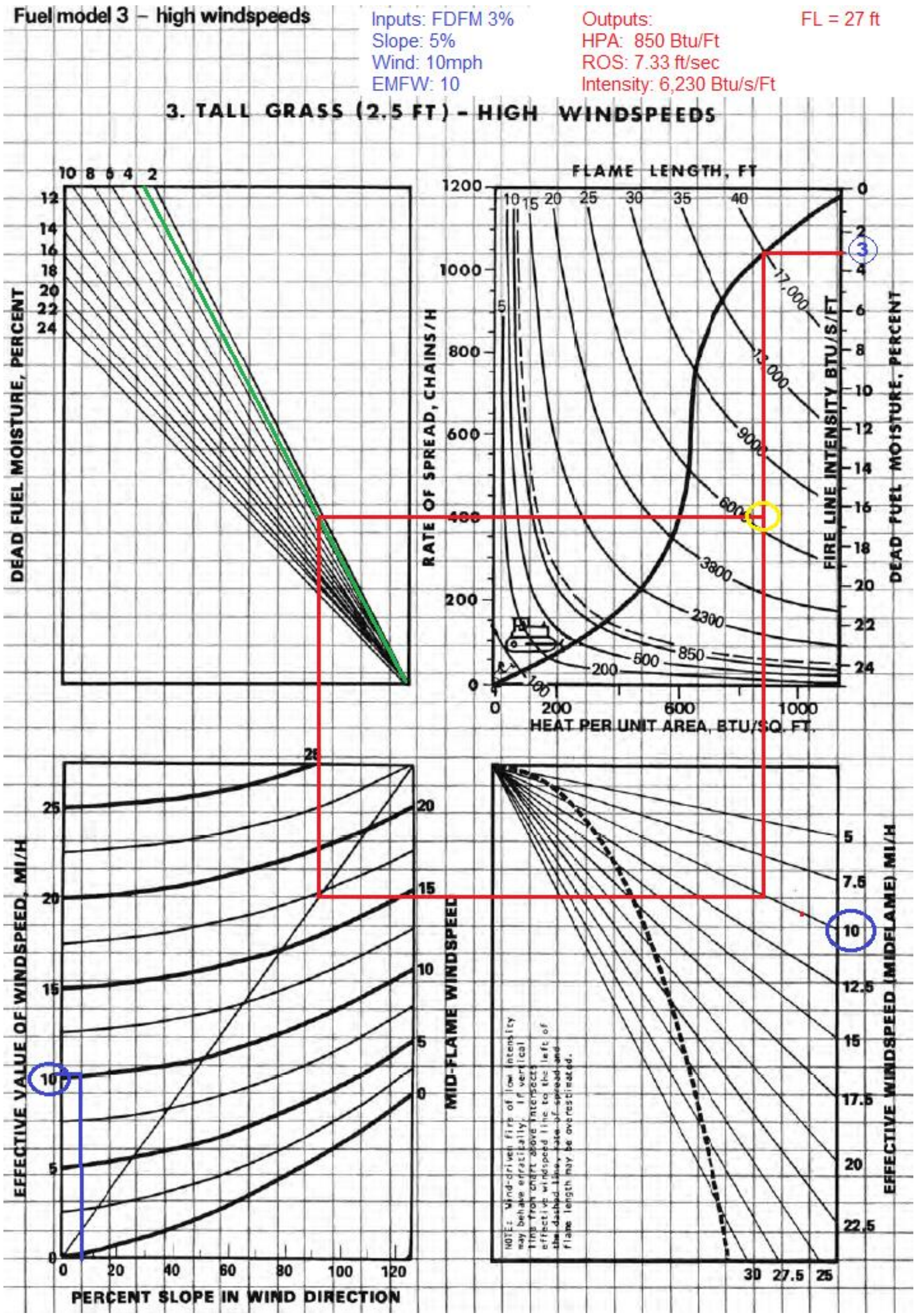
Following the Red line until it hits the 10mph wind speed line, a left turn is made to the other quadrant diagonal line called the "Turn line". Then you move vertically upward to the Green Line which is the next "Turn Line" and then turn RIGHT and intersect the initial vertical red line. Where these two intersect is the expected fire behavior in ROS, HPA, Intensity, and Flame Lengths.

If we follow the 6000 Btu/sec line vertically upward we can see that the estimated flame lengths are somewhere around 26 feet.

Looking in that same upper right box, in the lower left corner you will see a depiction of a dozer, to the lower left of that is a stick figure firefighter. These represent the areas where their maximum effectiveness is reached for these resources. This is another reason for Thermo-Dynamic planning and training. Both of these do not exist as of date for wildland firefighters.

We said you could break this up into manageable parts. So let us assume that you have a priority along the arc length of B-C. If the total arc length is 7967 feet, divide by 2 to obtain the length BC. 7967/2 = 3,983ft. This new section is 3,983 x 7.33 = 29,195 sqft. X 850Btu/ft = 24,816,081 Btu/sec. If you divide the 24,816,081 by 9457 you find you need 2,623 gallons. Approximately the capacity of 1 S64 or 1 MD87, 1-RJ85, 1-C130, etc. If you have none of these, then you may need to resort to fuel removal and remove 7.33 feet of line at a minimum. However, winds may suggest removing 1.5 or 2 times the active width pending fire fallout and what the PIG says, etc.

The Nomogram intensity of 6,230 Btu/s/ft means that .66 gallons of water will handle 1ft x 7.33ft of area if it is delivered every second. .66 x 60 = 39.6 gallons per minute at minimum. A 60gpm nozzle will only handle about 2 feet of width by itself. Then the fire is moved past you. Fuel Removal ahead of the front is the best option and if timed with a water drop can do real damage.


Fuel model 3 – high windspeeds
Inputs: FDFM 3%
Slope: 5%
Wind: 10mph
EMFW: 10
Outputs:
HPA: 850 Btu/Ft
ROS: 7.33 ft/sec
Intensity: 6,230 Btu/s/Ft
FL = 27 ft
3. TALL GRASS (2.5 FT) - HIGH WINDSPEEDS
DEAD FUEL MOISTURE, PERCENT
RATE OF SPREAD, CHAINS/H
FLAME LENGTH, FT
FIRE LINE INTENSITY BTU/S/FT
DEAD FUEL MOISTURE, PERCENT
HEAT PER UNIT AREA, BTU/SQ. FT.
EFFECTIVE VALUE OF WINDSPEED, MI/H
MID-FLAME WINDSPEED
EFFECTIVE WINDSPEED (MIDFLAME) MI/H
PERCENT SLOPE IN WIND DIRECTION
NOTE: Wind-driven fire of low intensity may behave erratically. If vertical line from chart above intersects effective windspeed line to the left of the dashed line, rate of spread and flame length may be overestimated.

Fuel Model 3, with Fuel Model 7 mixed.

<u>Ground Resources:</u> These are computed similarly with the exception being that once the amount of water is known, the individual responsible MUST know how to determine the ground logistics for the number of water tenders and or engines required, the amount of hose required, the size of the hose to help facilitate the necessary flow demands without incurring a severe degradation due to friction loss for the flow demand required.

As an example, 5,300 gallons every second (**<u>318,000 GPM</u>**), is a Multiple LAT requirement. However, this too can be broken up into manageable sizes. Say only 1,900 feet of the fire line that is of the highest priority. Then the entire loads are re-computed. 1,900ft x 6,230Btu/sec/ft =11,837,000 Btu/sec/ft. Next, divide the 11.8 million Btu figure by 1,134 to obtain 10,438 lbs per second. $\frac{10{,}438}{8.34} = $ 1,251 gallons per second. The same thermal capacity figure for water remains unchanged and is used again here as shown saving you a duplicative math step.

This drops the number of aircraft considerably and (1), 1300 gallon Tanker can make a precision strike provided this is communicated and planned out with ground crews, engines, and dozers in advance so that they make a coordinated strike at the same time and location for maximum effectiveness. It is a timed event!

The other Aircraft should be loaded, and in the area to help "maintain" the status quo once the plan is ready to be put into play. Retardant does NOT absorb any heat and off-gases phosphoric acid and ammonia if exposed to temperatures above 194°f. See Phos-Chek SDS. Retardant ideally should be used last, not first. Covered this in the FireBridge writing.

However, if the fire is reduced in its ROS, its intensity is likewise reduced. This would enable us to simultaneously set up support for lighter helicopters. For example, let us use 3 Type 3 helicopters using 180-gallon buckets with turns every 4 minutes from a planned dip site fed by water tenders as would normally be planned. The Equivalent Gallon Per minute rating (*EGPM*) for the helicopters must be determined and is computed by Bucket size, times the number of helicopters divided by the round trip time: $\frac{180x3}{4} = 135Egpm.$ This includes time in the dip and the drop.

Supplying remote dip tanks with water tenders, then the number of tenders needs to be computed so that an equivalent flow matching or exceeding what the helicopters are pulling is derived otherwise the helicopters become less effective and will be forced to shut down. Hence, the helicopters are your life-size pump impeller and will be cavitating.

If a 3,000-gallon tender requires 45 minutes for its round trip; then $\frac{3{,}000-10\%}{45} = 60gpm.$ Then, $\frac{135}{60} = 2.25, rounded\ to$ 3 tenders are required at a minimum to sustain NON-STOP operations for the proposed number of available helicopters. If this changes, such as 1 extra helicopter shows up, then the number of water tenders MUST go up. Otherwise, the helicopters pull away from the water source and will be forced to shut down.

The minimum tender requirement should be an NFPA-rated Fire Pump of 500GPM@150PSI. Each Engine and Tender should know how to engage in relay pumping. (Training that is not normally conducted).

This should be considered the initial attack estimates to establish your *baseline*. It will require adjustments as the fire progresses. Consulting the aircraft absorption capacity charts by the above methods mathematically (or by my book) will save an enormous amount of time in your calculations.

This paper does NOT cover fuel removal via Dozer in depth. However, a "*quick n dirty*" estimate can be made if you take the estimated carrier fuel HPA and multiply it by the blade finished cut width of a dozer you will have the amount of Equivalent Btu of fuel REMOVED from the incoming fire front. This could substitute for water use or be combined with water. Do not forget winds aloft vs fuel height.

As an example, using the fuel model 3, for the current conditions, a fuel loading of 850 Btu per square foot exists currently. If we use a D6 Dozer and shave off 1 foot of forward advancement we just removed 10,200 Btu. If this same dozer then tracks 100 feet it will have removed 10,200 x100 = 1,020,000 Btu worth. However, if a Dozer line is made 2 blades wide, then the conditions provided mean we can assume we removed 20,400 Btu worth in a single foot of forward travel for 24 feet of width.

Based upon the model methods of the day, such as the Nomograms that actual Engineers from the 1940s-1970s have worked out and proven and are further used to date in *Behave Plus* software, I for one have no problem sticking with a Nomogram for quick field estimates.

Training personnel on how to understand nomograms for Suppression and RX Holding functions and planning out potential heat generation problems will allow one to better determine resources and types for more effective cooling capacity. Randomly assigning Engines on a fire with this rate of spread and only a booster nozzle, especially when it's moving at 7 feet every second, isn't going to work.

The average booster nozzle on an engine flowing 20 gallons per minute (.33 gals/sec) will absorb 3,120 Btu/sec.

The average 1.5" combination nozzle on an engine flowing 60 gallons per minute (1 gal/sec) will absorb approx. 9,365 Btu/sec.

<u>Absorption vs ROS issues:</u> If we stick with our current Fuel Model 3, let us attempt to show a potential problem many may find themselves getting into. The fire is generating 6,230 Btu per second, and the nozzle flowing 20GPM is absorbing 3,120 Btu/sec. Then it takes 2 seconds worth to cool that 1 foot x 7.33 foot area. However, in those 2 seconds that fire 1 foot away is now 14.66 feet past you.

If you were using a 1 ½" combination nozzle it would take .6 seconds and you could only cover 1.5 times the 1x7ft area, that is, 10.9 square feet worth of area total, and would be facing the same time and distance issues. In .6 seconds the fire still moves at a rate of 4.4 feet per second. This is still a longer stride than what nearly every firefighter can walk at. The Flame lengths are approx. 26 feet.

Knowing this information would allow one to know that selecting an aircraft of appropriate size capacity, with water and NOT retardant first, which, can remain on station longer and be more suited to the needs of ground resources becomes a much better option. A Type 3 Helicopter with a 180-gallon bucket can bring 1.6 million Btu of cooling to the fire. This would allow us to approximately cover an area of 256 square feet at a time. Having 3 type 3's would allow for 768 square feet or a linear distance of approx. 105 feet.

$$T3\ Coverage\ Area = \frac{1{,}600{,}000^{BtuCap}}{6{,}230^{intensity}} = 256^{ft2}$$

The reality is the coverage distance will be greater or lesser pending drop height, width of pattern, etcetera, however, the point is that as long as the amount of heat capacity can be delivered to the carrier fuels, you will see reductions in Rate of Spread and consequently intensity.

If one never cools a fire by water, and subsequently only drops retardant ahead of the fire you are thereby doing nothing to cool the fire. One might as well be dropping nothing on a fire.

Lastly, 1 pound of water is approximately a 3-inch cube. At 50 degrees water temperature, at 8,000 feet, the 3-inch pound will absorb 1,117 Btu. At 5,000 feet that 3-inch cube can absorb 1,123 Btu worth of heat. At sea level, the same 3-inch cube will absorb 1,132 Btu worth. Simply consider how much heat such a small volume can hold!

To make this simpler, use the quick and dirty rules for calculating needs.

8k = 1100

5k = 1120

0K = 1130

Again, by example, our fire generated 49,640,584. Rounding to 50,000,000 and dividing by 1130 tells us we need to somehow deliver 44,247 lbs per second on it and that equals 5,300 gallons every second for the entire arc length. Once you tell someone what they have to have, if they refuse to obtain that, or do not empower you to get the resources to facilitate such, anything thereafter is on them.

At the end of the day, all that can be affirmed is the fact that the Thermo-Dynamic relationships of a fire ground are clear in that a fire with a certain generated intensity will demand a certain volume for cooling. You can get a good thermometer and test these figures out on your gas stove at home. The problem of delivery, transport, and any other factors not within your control is not and should not be the deciding issue here. It is simply being stated that for any fire encountered anywhere in the world, for any intensity, if that intensity is not met with the equal capacity of cooling or Btu removal, it's not going out on YOUR terms.

COOL IT RETARD IT DOZE IT

FIRE BRIDGE

ENGINEERS MAKE IT HAPPEN

Joseph Moylan

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Aircraft Data:

Aircraft Type	Category	Cruise Speed		Capacity indivŦ		Cap Total	Btu total Cap‡
1,2,3	rotor/fix	Kts	Mph	LC95	Water	Gallons	Million Btu's
1- RJ85	Fixed	330	380	545	2455	3000	28.1
1- BAE 146	Fixed	330	380	545	2455	3000	28.1
1-C130MAFF	Fixed	238	275	545	2455	3000	28.1
1-MD-87	Fixed	347	400	545	2455	3000	28.1
1-P3A	Fixed	330	380	545	2455	3000	28.1
1-L188	Fixed	310	356	600	2700	3300	30.1
1-C130	Fixed	238	275	727	3273	4000	37.5
1-737-300	Fixed	250	287	727	3273	4000	37.5
1-DC10	Fixed	420	485	1709	7691	9400	88.1
1-747	Fixed	490	565	3490	15709	19200	179.8
1-CH53E	Rotor	150	137	na	na	2000	18.7
1-CH46 sk	Rotor	121	140	na	na	224	2.1
1-CH47D	Rotor	119	137	na	na	2000	18.7
1-S61	Rotor	133	154	na	na	1000	9.3
1-S64	Rotor	91	105	na	na	2650	24.8
1-S70i	Rotor	159	183	na	na	1000	9.3
1-kmax	Rotor	79	91	na	na	660	6.1
1-AS332L	Rotor	135	156	na	na	2000	18.7
1-B107Vertol	Rotor	121	140	na	na	1000	9.3
1-B234CHnk	Rotor	119	137	na	na	3000	28.1

Use with Fire Behavior Nomograms!

NOTE: The aircraft data sections for pp 129 & 130, show listings for Maximum Gallon Capacities and may not be reflective of those used. The *Btu* figures are displaying *Btu* Capacity should those maximum capacities in water be available and utilized. Review "Fire Behavior Nomograms w/Engineers Q-ref" on the wildfireengineer.com website

Aircraft Data cont'd:

Aircraft Type	Category	Cruise Speed		Capacity indivŦ		Cap Total	Btu total Cap‡
1,2,3	rotor/fix	Kts	Mph	LC95	Water	Gallons	Million Btu's
2-CL215	Fixed - S	189	233	236	1064	1300	12.17
2-CL415	Fixed - S	194	223	294	1326	1621	15.2
2-C580	Fixed	270	310	381	1719	2100	19.7
2-Q400	Fixed	370	425	480	2162	2642	24.7
2-UH1H	Rotor	108	125	na	na	324	3.03
2-B205++	Rotor	108	125	na	na	324	3.03
2-B212	Rotor	99	115	na	na	360	3.37
2-B412	Rotor	121	140	na	na	360	3.3
3-802	Fixed	149	172	145	655	800	7.5
3-802F	Fixed	192	221	8.2*	811.8	820	7.7
3-S2T	Fixed	234	270	218	982	1200	11.2
3-206B	Rotor	99	115	na	na	120	1.1
3-206L	Rotor	104	120	na	na	120	1.1
3-AS350	Rotor	139	161	na	na	180	1.6
3-MD500	Rotor	125	144	na	na	120	1.1
3-B407	Rotor	132	152	na	na	180	1.6

Ŧ = Water to Retardant ratios(5.5:1). Handy for tender shuttle relays supplying water

‡ Total BTU heat absorption capacity at 5,000ft alt. water temp 50degrees if entire load is water only

S = Scooper

* = foam concentrate i.e. Silv-Ex class A in place of LC95 @ 1%

Use with Fire Behavior Nomograms!