The Time-lapse Holy Grail

How to use GBTimelapse with Autoramp
For Expert Users – and the curious!
By Mike Posehn, Ph.D., aka Dr. Timelapse

A great time-lapse is all about change and movement. However, changing light conditions often wreak havoc on your footage, resulting in brighter and darker frames which appear as annoying flicker in your time-lapse.

Capturing *a smooth time-lapse* of a sunset *from full daylight to darkest night, without flicker,* has been called the "Time-lapse Holy Grail" because it has been practically impossible to achieve.

However, you can now achieve this Holy Grail with GBTimelapse! In this White Paper, I describe the challenge of The Time-lapse Holy Grail and take you through the process of getting it with GBTimelapse.

GBTimelapse has been used for National Geographic videography, the Brazil 2016 Summer Olympics preparations, Thursday Night Football network footage, and much, much more.

GBTimelapse is a powerful tool that gives you control over many factors of your time-lapse capture. This White Paper will give you examples of the high tech calculations going on under the hood, what factors you can modify, and ideas for how to use GBTimelapse to best suit your needs.
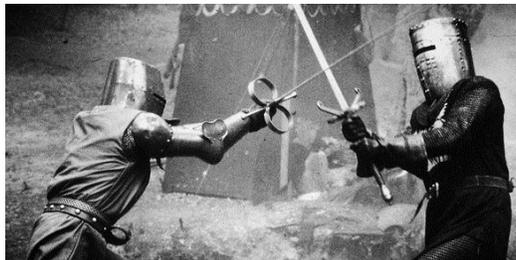
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Or, browse through the full paper to get into technical detail.**

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1. The Problems

The basic problem of the Time-Lapse Holy Grail is that there's a massive difference in the amount of light between day and night, and no one easy way to step through that difference. A smooth time-lapse needs to transition evenly, but it's definitely not as easy as it may seem. There are multiple ways to step down (or up) the amount of light your camera is receiving, but each of those methods has a potential pitfall for our goal of a smooth transition. As we'll see later in this White Paper, GBTimelapse is programmed to automatically make optimal adjustments for you, and to allow you to make further detailed tweaks if you prefer.

Problem: Daylight and Night Exposures are over 20 stops apart

What is a stop? A "stop" is a relative measurement of light. Double the light is one stop brighter. Half the light is one stop darker.

Let's look at an example. A typical daylight sunny sky exposure is f/16, ISO 100 at 1/100 second. A typical starry night exposure showing the Milky Way is f/2.8, ISO 3200 at 30 seconds.

Daylight: f/16, ISO 100, 1/100 sec   **Night: f/2.8, ISO 3200, 30 seconds**

Sample stop conversion:
From f/16 to f/2.8 is 5 stops
From ISO 100 to 3200 is 5 stops
From 1/100 second to 30 seconds is over 11 stops
Total change = 21 stops

Since one stop is a factor of two, twenty-one stops is a factor of 2^{21}, over 2 million (2,097,152 to be exact). This means that *there is literally over 2 million times more light in the daytime than the night!*

Problem: Preset camera settings are not gradually spaced

To eliminate flicker, *the camera exposure settings must be changed very gradually over a range of more than twenty stops.* But camera apertures and shutter speeds can't be changed gradually because the presets are normally spaced at 1/3 stop intervals. Changing exposures in 1/3 stop steps shows up as abrupt brightness changes, or flicker. I'll address how GBTimelapse solves this problem in the GBTimelapse Solutions section.

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Problem: Sky brightness rate of change varies with latitude

When you're making your time-lapse for a full sunset or sunrise, you're also running into the problem of twilight. *In the twilight period, the brightness of the sky changes more or less rapidly depending on your latitude.*

An example is a recent time-lapse I made at 38 degrees latitude. At this particular latitude, civil twilight ended 53 minutes after sunset and nautical twilight ended 1 hour and 15 minutes after sunset. If I had been nearer the equator, these times would be *much shorter*, and at higher latitudes they would be *much longer*.

In AutoRamp Expert Mode, GBTimelapse allows you to enter your GPS coordinates. GBTimelapse will then automatically calculate the period of twilight brightness, and adjust for the correct rate of brightness change. ***You don't have to enter your GPS coordinates, but doing so enables GBTimelapse to be exceptionally precise in controlling the transition of your camera exposure during twilight, at your individual latitude.***

FOR THE CURIOUS… TWILIGHT & DEFINITIONS:

The horizon *is geometrically 90° from the local vertical direction.* - US Naval Observatory

Sunset *is defined as when the upper edge of the disk of the sun is on the horizon.* - US Naval Observatory

Civil twilight *is defined to end in the evening when the center of the Sun is geometrically 6 degrees below the horizon. This is the limit at which twilight illumination is sufficient, under good weather conditions, for terrestrial objects to be clearly distinguished; at the beginning of morning civil twilight, or end of evening civil twilight, the horizon is clearly defined and the brightest stars are visible under good atmospheric conditions in the absence of moonlight or other illumination.* - US Naval Observatory

Nautical twilight *is defined to end in the evening, when the center of the sun is geometrically 12 degrees below the horizon. At the beginning or end of nautical twilight, under good atmospheric conditions and in the absence of other illumination, general outlines of ground objects may be distinguishable, but detailed outdoor operations are not possible, and the horizon is indistinct.* - US Naval Observatory

Twilight and latitude *"The length of twilight after sunset and before sunrise is heavily influenced by the latitude of the observer. In the Arctic and Antarctic regions, twilight (if there is any) can last for several hours. There is no civil twilight at the poles within a month on either side of the winter solstice. At the poles, civil twilight can be as long as two weeks, while at the equator, conditions can go from day to night in as little as twenty minutes. This is true because at low latitudes the sun's apparent movement is perpendicular to the observer's horizon. As one gets closer to the Arctic and Antarctic circles, the sun's disk moves toward the observer's horizon at a lower angle. The observer's earthly location will pass*

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through the various twilight zones less directly, taking more time." - Twilight, Wikipedia

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2. GBTimelapse Solutions

Hi there, Expert User! When you make a time-lapse with GBTimelapse, the AutoRamp function is performing a ton of calculations for you behind the scenes, and providing options for you to input more information if you choose. This section gives you a peek at what's going on inside the software.

Solution: AutoRamp handles *bulb ramping* for you

As we learned in The Problems section, to get the smooth, flicker free time-lapse that we're after, we're going to have to make a seamless exposure transition over a massive difference in available light. As noted, the difference between day and night brightness is easily 20 stops.

The only way to gradually change an exposure is to use a camera's bulb mode. "Bulb ramping" means gradually changing the bulb exposure time. The term "bulb" is a reference to old-style pneumatically actuated shutters. For old school shutters, squeezing an air bulb would open the shutter, and releasing the bulb would close it.

Nowadays, a bulb exposure can be controlled electronically with a command sent to open the shutter followed by a command to close the shutter. By using Bulb mode, the shutter speed can be changed in increments as small as 0.001 seconds. A tiny change in shutter speed produces such a small change in brightness that flicker is avoided.

When a camera operates in Program, Av, or Tv mode the camera sensor determines the correct exposure at the instant the shutter button is pressed. But when a camera is in Bulb mode, it is up to the photographer, or a system controlling the camera, to determine the correct bulb duration required to produce a properly exposed image.

There are three ways to set the bulb duration for a time-lapse:
- **A predetermined script** that ramps the bulb duration according to a preset schedule. This may not be practical because of unexpected variations in sky brightness due to cloud cover, obstructions, the moon and artificial lighting. *A hardware controller following a script won't be performing GBTimelapse's precise calculations, tailored to your GPS location and the individual brightness characteristics of your evolving scene.*

- **Manual adjustment** of bulb duration is possible, but requires the continuous attention of the photographer. There are some semi-automatic hardware bulb ramping devices to make this easier for the photographer, but constant vigilance and great care must be taken to not introduce unwanted brightness variations. *If you are manually controlling the shutter over the entire period of your time-lapse, your results may be wildly unpredictable, and you definitely won't be relaxing in your lounge chair with a beer.*

- **Automatic control with GBTimelapse** is based on real-time sky brightness measurements, with an integrated calculation of the rate of brightness change when GPS coordinates are entered. *GBTimelapse offers automatic, smoothly continuous exposure adjustments tailored exactly to your lighting situation,*

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with the minimum photographer intervention. And there's no other product like this on the market!

Solution: AutoRamp and Brightness Sensitivity

The brightness of the sky during your time-lapse also depends on cloud cover, horizon obstructions (terrain and buildings), the position and phase of the moon, and artificial lighting. GBTimelapse automatically compensates for these large-scale brightness effects.

At the same time, the AutoRamp function gives you the option to choose the sensitivity level of the software to passing brightness changes, like cloud cover, or artificial lights turning on/off. By adjusting the sensitivity slider, you can make GBTimelapse more or less sensitive to these smaller, more momentary changes in brightness.

Solution: Enter your GPS Coordinates

As discussed in The Problems section, the brightness of the sky during the delicate period of twilight varies greatly depending on your latitude. GBTimelapse allows you to input your GPS coordinates. You don't have to, but if you do specify your GPS info, the software will automatically adjust the rate of change of your exposure in the twilight period, tailoring your time-lapse to the conditions at your latitude.

Also, GBTimelapse computes the sun angle from the local time and GPS coordinates to ensure accuracy regardless of latitude. So your GPS information will always be useful for achieving smooth time-lapse, not just in twilight scenes.

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3. Photography Basics

Getting good time-lapse footage is easier with a basic understanding of camera exposures. A general knowledge of stops, shutter speeds and ISO values is helpful. The concept of exposure reciprocity aids us in converting f-stops to ND filters to shutter speeds, as we calculate the exposure across the 20+ stop difference between day and night.

Controlling exposure with your digital camera

The four ways to control the exposure of a DSLR camera:

- **Aperture (Av):** Each f-stop lets in half as much light as the one before it, i.e.1.4, 2.0, 2.8, 4.0, 5.6, 8, 11, 16, etc.
- **Shutter Speed (Tv):** Each shutter speed lets in light for half as long as the one before it, i.e. 1, ½, ¼, 1/8, 1/15, 1/30, 1/60, etc.
- **Sensitivity (ISO):** Each ISO is twice as sensitive as the one before it, i.e. 100, 200, 400, 800, 1600, 3200
- **Neutral Density filters (ND):** Each filter lets in half the light as the one before it, i.e. ND2, ND4, ND8, ND16

What is a Neutral Density filter?

"A Neutral Density filter is to a camera lens what a pair of sunglasses is to a human."-Peter Hill

Neutral Density filters are made with increasing levels of density, equivalent to stops. By adding ND filters we can either increase the exposure time or decrease the f-number. Below is a table of commonly available neutral density filters and their filter values.

Neutral Density filter values

ND Filter	# of Stops
ND 0.3 2x	1 stop
ND 0.6 4x	2 stops
ND 0.9 8x	3 stops
ND 1.2 16x	4 stops
ND 1.8 64x	6 stops
ND 3.0 1024x	10 stops

What is Reciprocity?

In photography there is an inverse relationship between the aperture and the exposure time. If you double the area of the aperture, then twice the light passes through the lens, so you can halve the exposure time (and vice versa). There is also an inverse relationship between the ISO and the exposure time. If you double the ISO the light sensitivity is doubled, so you can halve the exposure time

The Sunny 16 Rule

The "Sunny 16" exposure = f/16, ISO 100, at 1/100 second

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"In photography the 'Sunny 16 rule' is a method of estimating correct daylight exposures without a light meter. The basic rule is: on a sunny day set aperture to f/16 and shutter speed to the reciprocal of the ISO setting for a subject in direct sunlight." - Wikipedia

What is the Exposure Value (EV)?

We define the Exposure Value of a setting as the number of stops from its "Sunny-16" reference value.

For example:
Since f/11 lets in twice the light as f/16, its EV is +1
Since 1/200" lets in half the light as 1/100", its EV is -1
Since ISO 800 lets in eight times more sensitive than ISO 100, its EV is +3

Exposure Values of Common Camera Settings

Exposure Value	Tv	Av	ISO	ND Filter
11	20"			
10	10"			
9	5"			
8	2.5"			
7	1.3"	f/1.4	12800	
6	0.6"	f/2.0	6400	
5	0.3"	f/2.8	3200	
4	1/6	f/4.0	1600	
3	1/13	f/5.6	800	
2	1/25	f/8	400	
1	1/50	f/11	200	
0	1/100	f/16	100	
-1	1/200	f/22	50	ND0.3 2x
-2	1/400	f/32		ND0.6 4x
-3	1/800	f/45		ND0.9 8x
-4	1/1600			ND1.2 16x
-5	1/3200			ND1.5 32x
-6				ND1.8 64x
-7				ND2.1 128x
-8				ND2.4 256x
-9				ND2.7 512x
-10				ND3.0 1024x

What is the Total Exposure Value (TEV)?

The Total Exposure Value (or TEV) of a camera setting incorporates the aperture (Av), shutter speed (Tv), ISO and ND filter. By definition a TEV value of 0.0 matches a "Sunny-16" exposure. If a scene is darker than "a subject in direct sunlight" it requires a positive TEV. If the scene is brighter, it requires a negative TEV.

The TEV is calculated by adding the relative Tv, Av, ISO and ND filter exposure values relative to their sunny-16 values.

$$TEV = EV_{Tv} + EV_{Av} + EV_{ISO} + EV_{ND}$$

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where

$$EV_{Tv} = \text{Log}_2(Tv) - \text{Log}_2(0.01)$$
$$EV_{Av} = \text{Log}_{\sqrt{2}}(16) - \text{Log}_{\sqrt{2}}(Av)$$
$$EV_{ISO} = \text{Log}_2(ISO) - \text{Log}_2(100)$$

As the sun sets, the sky gets darker and the TEV gets larger. At night a f/2.8, ISO 3200, 30-second exposure has a TEV of about 21.

The graph below shows how TEV can range from 0 in daylight to over 20 at night. This TEV graph was made to show a noon-to-noon 24 hour time-lapse shot at a 60 second time interval (1,440 images in 24 hours). You can see that the daytime TEV began at 0.0, and rapidly rose to 20 as the sun set. It stayed at a constant TEV of 20 because the exposure was limited to f/2.8, 30s and ISO 1600. In the morning the TEV rapidly decreased back to 0.0 as the sun rose.

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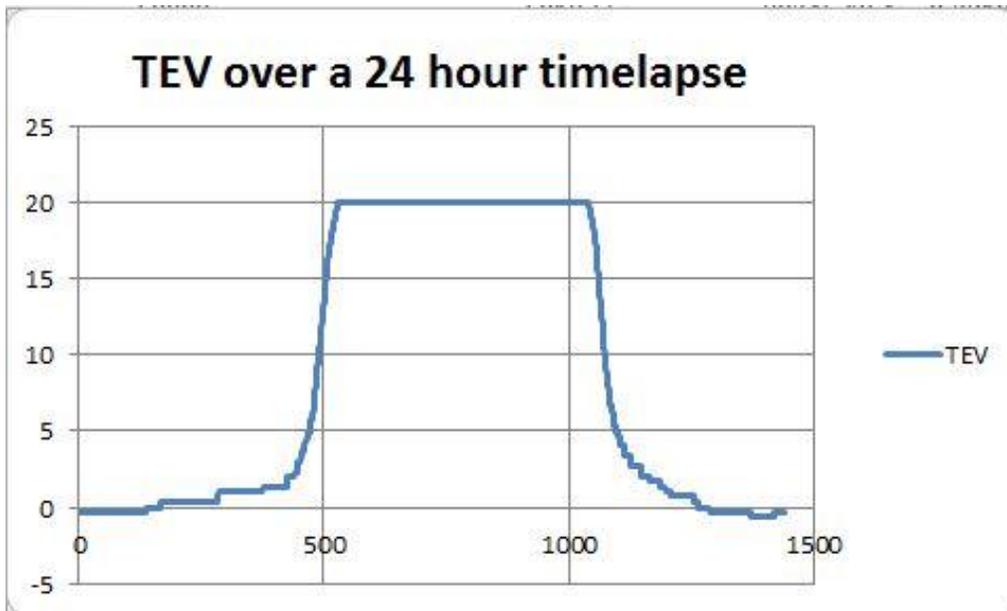
4. Complications

If you are an expert user striving for perfection, you'll be interested in these technical details. In practice, exposure reciprocity can fail because of inaccuracies in the lens f-numbers and ND filter ratings. GBTimelapse will automatically use reciprocity to convert stops, exposure and ND filters to cover the 20+ stop difference between day and night. However, the software may calculate correctly, but in practice we find that the numbers on the labels – for f-stops and ND filters – simply aren't accurate!

<u>Complication</u>: Lens f-Numbers are not accurate

Lens f-numbers are approximations and are not exact. Lens f-numbers are approximations that are accurate enough for normal photography, but can cause reciprocity failure when doing bulb ramping.

GBTimelapse contains calibrated lens information for a wide variety of lenses. For lenses in the database, all you need to do is select your lens. For lenses not in the database, you can calibrate your lens automatically through GBTimelapse. Below, I've compiled a table of f-numbers and their actual values for a Canon 16-35 f/2.8 USM lens.

Rated f-Stop	Actual f-number	Actual EV
2.8	2.988	4.84
3.2	3.132	4.71
3.5	3.31	4.55
4	3.865	4.10
4.5	4.245	3.83
5	4.648	3.57
5.6	5.458	3.10
6.3	5.861	2.90
7.1	6.52	2.59
8	7.665	2.12
9	8.361	1.87
10	9.228	1.59
11	11.08	1.06
13	12.216	0.78
14	13.305	0.53
16	16	0.00
18	17.424	-0.25
20	19.217	-0.53
22	22.717	-1.01

Above, actual f-numbers for a Canon 16-35 f/2.8 USM lens

You can see that the actual values differ by nearly 10% from the rated f-numbers. If you made a reciprocity calculation based on the f-Number, there would be a noticeable brightness change in the image. For example, if we decrease an f-number from f/4 to f/2.8 and halve the bulb time, the exposure may not be exactly the same. This is because the lens f/2.8 iris area is not precisely double the f/4 iris area. The actual difference between

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f/2.8 and f/4 is 0.74 stops (4.84 – 4.10), not 1 stop. Clearly it is better to use a calibrated lens when doing an Av reciprocity calculation!

<u>Complication</u>: ND Filter ratings are not accurate

Although an ND8 filter may be rated at 3 stops, its actual value may be off by more than ten percent. ND filter ratings are approximations that are accurate enough for normal photography, but can cause reciprocity failure when doing bulb ramping. I have personally measured a 3-stop ND8 filter that was actually 3.28 stops and a 4-stop filter that was actually 4.44 stops. Clearly a bulb time calculation not based on the actual value would lead to a brightness change.

GBTimelapse was created to solve this complication. ***You can use GBTimelapse to calculate your actual ND filter rating – this is an automated process with the AutoRamp function.***

<u>Complication</u>: Aperture Flicker

Because the camera iris is a mechanical device, there are differences in the exact size of the aperture for successive actuations. These small differences in aperture result in frame-to-frame luminance variations that show up as flicker when played back. Aperture flicker seems to be less evident with smaller f-numbers (larger apertures). ***GBTimelapse automatically uses the smallest possible f-number to minimize aperture flicker.***

<u>Complication</u>: Short bulb durations are inaccurate

Short bulb times near a camera's minimum value are not very accurate. A 0.01 second variation in a 0.1 second bulb time can produce noticeable flicker, but a 0.01 second variation in a 1.0 second bulb time is much less noticeable. For this reason it's best to use a longer bulb time whenever possible. ***This is a good reason for using ND filters. When you use ND filters, you are using a longer bulb time.***

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5. Holy Grail How-To

Below is an outline of the general process for achieving the Time-lapse Holy Grail for a sunset. Note that the stages highlighted in grey will be *automatically* performed by GBTimelapse.

1) Input your GPS coordinates into GBTimelapse's AutoRamp function
2) Calibrate your ND filters with AutoRamp (you only have to do this once)
3) Set your lens, or calibrate your lens with AutoRamp
4) Begin in daylight, putting one or more ND 8x filters on the camera lens
5) GBTimelapse controls initial bulb ramping, gradually increasing the bulb time to 0.8"
6) Remove each ND8 filter after the bulb time increases to 6.4"
7) GBTimelapse controls the ISO, stepping the ISO from 100 up to 3200
8) GBTimelapse gradually increases bulb time to 30"

Why use Neutral Density filters? *Using ND filters will enable us to keep the camera in bulb mode, so that GBTimelapse can use the most precise and optimal shutter settings possible. Trying to cover the twenty-one stop sunset range with bulb ramping alone would require the bulb time to ramp from 0.2 seconds to 209,715 seconds! Clearly, as it gets darker during a sunset, we need to remove the ND filters and increase the ISO to keep the bulb time under 30 seconds.*

How many Neutral Density filters should I use? *Use sufficient ND filters to enable you to use bulb mode for the duration of the time-lapse. For example, add three ND8x filters to reduce the amount of light by nine stops from (f/16, ISO 100, 1/100) to (f/2.8, ISO 100 and 0.2").*

Here's the detailed process for the example sunset:
    Phase 1:
    f/2.8, ISO 100 at 0.2" with 3 ND8x filters, daylight start
    Start with three ND8 filters for a total of stops and start the time-lapse at f/2.8 instead of f/16. This minimizes the effect of aperture flicker and avoids the need to calibrate the lens f-numbers. However, it does require accurate calibrations for the three ND filters.

    Phase 2:
    f/2.8, ISO 100 at 0.8" with 3 ND8x filters, after initial bulb ramping
    Gradually increase the bulb time to a longer and more accurate duration. It's better to let the bulb time increase to a value nearer one second to minimize flicker due to bulb timing inaccuracy. For this example, I'll assume the time has increased to 0.8 seconds.

    Phase 3:
    f/2.8, ISO 100 at 0.8", after removing the third filter
    Remove an ND filter each time the bulb time increases to 6.4 seconds and then decrease the bulb time back to 0.8 seconds.

    Phase 4:

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f/2.8, ISO 3200 at 0.8", after ISO stepping
Continue ISO stepping each time the bulb duration doubles

Phase 5:
f/2.8, ISO 3200 at 30", at full darkness
Gradually increase the bulb time to its maximum value

Sunrise Holy Grail

To capture a sunrise time-lapse, the process described above is reversed. Instead of removing filters as it gets darker, filters are added as the sky gets brighter.

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6. Holy Grail Case-Study:
GBTimelapse *Expert Method*

Expert Method

Below are images from a sunset time-lapse captured with GBTimelapse using a Canon 5D Mk II with 16-35mm lens.

Daylight: f/2.8, ISO 100, 0.5" and 3 ND8x   Night: f/2.8, ISO 3200 at 30"

Here's how I did it:
- I entered my GPS coordinates into AutoRamp
- I made sure my lens was calibrated, and my lens was set in AutoRamp
- I put three ND8x filters on the camera lens, to enable a bulb time of 0.5" at f/2.8
- I began the time-lapse
- As the sky darkened at sunset, GBTimelapse gradually increased the bulb time
- Every time the bulb time exceeded 8 seconds, I removed one of the ND filters
- Because I had calibrated the value of each ND filter using AutoRamp, GBTimelapse decreased the bulb exposure precisely
- Later, as the sky darkened further, GBTimelapse automatically stepped the ISO down –from 100 to 3200 – each time the bulb exposure reached 24 seconds

Technical analysis of this time-lapse:

Below is a graph of the image luminance over the duration of my example time-lapse. You can see some initial variations over the first half hour during daylight when the bulb duration was nearer the camera's minimum. Most of the luminance variation is due to changes in the sky brightness – cloud cover, cloud illumination, passing boats, passing airplanes, etc. The resulting video showed no significant flicker.

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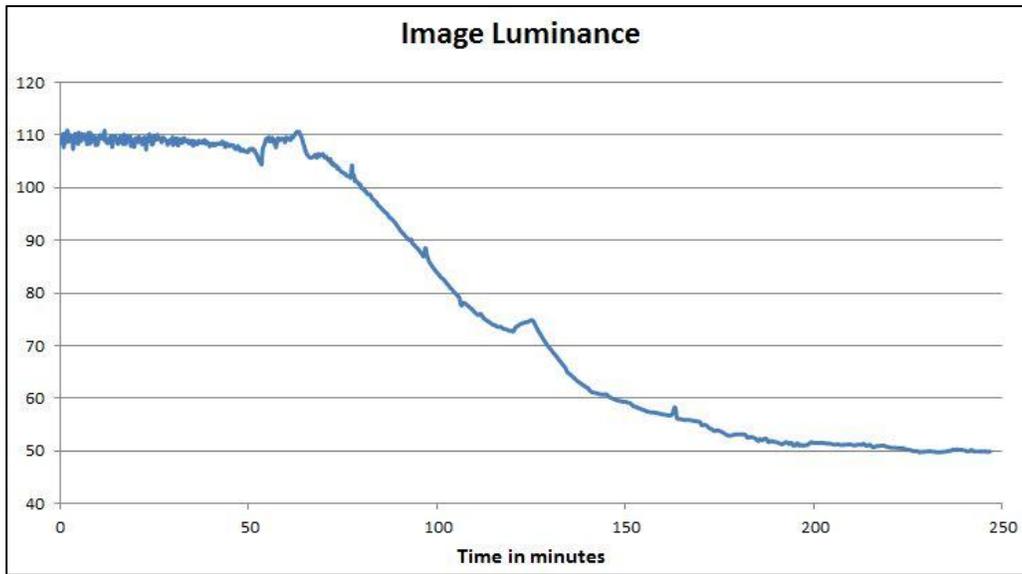
The chart below shows how the bulb exposure time varied over the three hour duration of the sunset time-lapse.
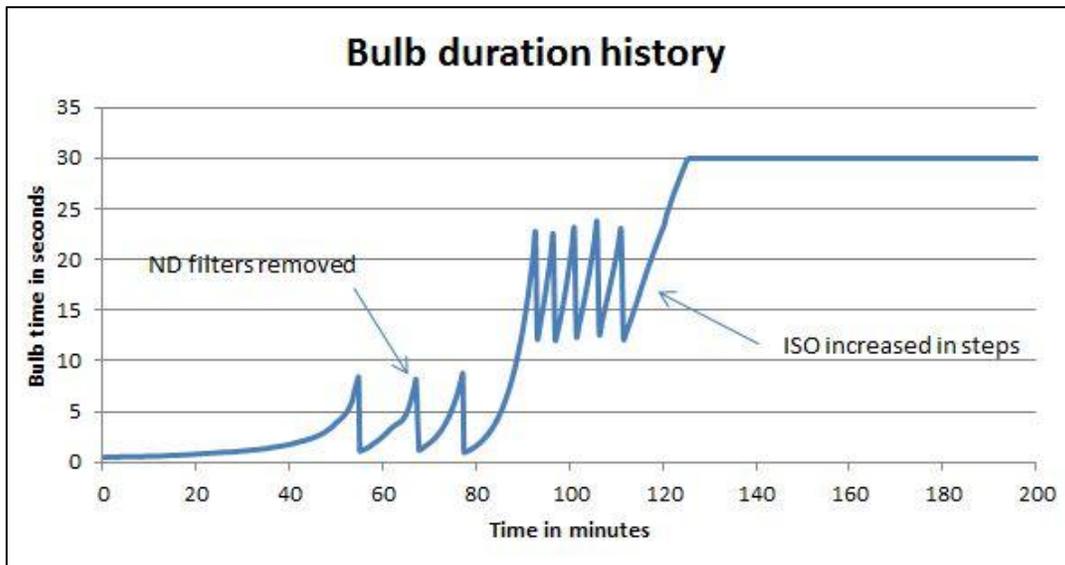
AutoRamp also adjusted the time-lapse interval between images to make a smooth transition from 10 seconds during daylight to 33 seconds at night.

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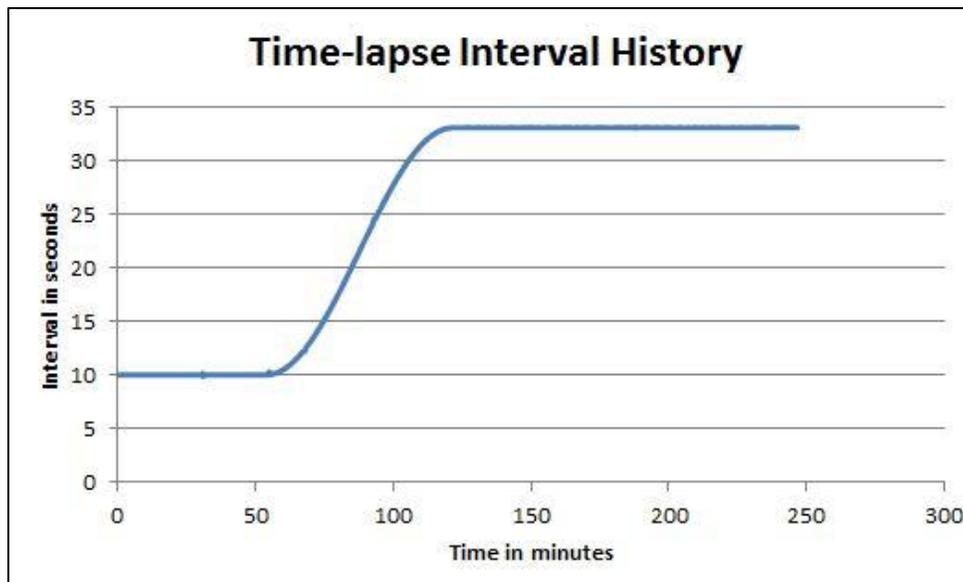
How well did it work? Check it out for yourself: the resulting time-lapse is the first scene in the YouTube video at **http://youtu.be/ebySUnXKgRw?hd=1**

EXPERT METHOD PROS: Amazing, un-paralleled results!

EXPERT METHOD CONS: If you're not interested in getting involved with the full Neutral Density filter process, you can keep it simple. With just one ND filter, you can achieve similar results through the Easy Expert Method.

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7. Holy Grail Case-Study:
GBTimelapse *EASY Expert Method*

EASY Expert Method
The EASY Expert Method only requires one Neutral Density filter.

The sunset time-lapse in the Expert Method Case Study could have begun with only one ND8x filter at f/22. AutoRamp would have used Av stepping to reduce the aperture down to f/2.8 before the one filter would need to be removed. To do this effectively, you still need select your lens in AutoRamp, and make sure it is calibrated.

The Easy Expert Method may not produce the full "Holy Grail" quality results because of aperture flicker (at higher f-numbers). However, this slight flicker can usually be removed with GBDeflicker. GBDeflicker is available as a standalone application, or an Adobe Plugin. For more details, check it out here.

EASY EXPERT PROS: Easy, fantastic results, especially when used in conjunction with GBDeflicker. It's simpler to only remove one filter, and it's also less expensive to only buy one filter. If there is flicker remaining, it can usually be removed with GBDeflicker.

EASY EXPERT CONS: If you're a hands-on expert on a quest for the perfection of the Grail, try out the full Expert Method.

8. Conclusion

As we've seen in this White Paper, GBTimelapse AutoRamp Expert Method is designed to automate and streamline the process of achieving the Time-lapse Holy Grail. Through the Problems, Solutions, How-To and Case Studies, you've learned how to consistently get incredible time-lapse footage in the most extreme lighting situation – full daylight to darkest night.

Summary of the features of AutoRamp in Expert Mode:
- Continuously adjusts the *bulb duration to maintain a desired image luminance*, adapting to changes in lighting caused by clouds, moon, artificial lights and any other causes
- Uses the *brightness history of captured images*, instead of an external light meter
- Uses your *GPS coordinates* to determine brightness rate of change at twilight, and to calculate the sun angle
- Gradually adjusts the *time-lapse interval* from a shorter value during daylight to a longer value, after twilight
- Optionally adjusts the *target luminance* to a lower value after sunset, so the image gradually darkens, during twilight
- Optionally adjust the *white balance* from a higher daylight color temperature to a lower night color temperature

For more information:
Do a free trial, purchase or learn more about GBTimelapse
Do a free trial, purchase or learn more about GBDeflicker
Stay current with my blog at http://tlapse.blogspot.com and newsletter

9. References

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