CAMERA LENS DETERMINATION

Abstract

This document details some important parameters for high-speed videos, specifically in reference to the AWT, and the general process followed to specify the 20 mm lens on the AWT

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High-Speed Video Parameters

A key element of testing cardiovascular devices is capturing high-speed video to better understand it, there are a few parameters to keep in mind.

Frame rate

When capturing video of a valve the first decision to make is what speed you would like to capture the video at. Most web cams and other digital cameras capture video in the 30-60 FPS range, however, the journal of motion picture engineers classifies high speed video as anything over 250 fps.

To help illustrate how frame rate is important we will discuss testing an aortic valve undergoing hydrodynamic flow testing at 70 beats per minute with a systolic duration of 35%. This valve has a complete cycle length of 0.857 seconds. In this period the valve is in systole for approximately 0.299 seconds and may have a closing time around 0.025-0.035 seconds. Table 1 below shows the number of frames in each portion of the valve cycle that can be captured with different frame rates. Additionally, the attached video demonstrates how frame rates affect the video.

Table 1: Example of number of frames acquired in different portions of valve cycle with various frame rates

Frame Rate (FPS)	Number of frames in systole	Number of frames in diastole	Number of frames in Valve closure
60	18	33.4	1.5
125	37.5	69.6	3.125
250	75	139.3	6.25
500	150	278.6	12.5
1000	300	557.1	25

Typically, a frame rate of 500-1000 fps is used to best capture the valve opening and closing, which only increases during accelerated wear testing. Capturing a video in as high frame rate as possible will give you a detailed video of the valve opening or closing but an increased frame rate also means a higher shutter speed therefore reducing the amount of light entering the camera which results in a higher required power draw from the external light source. Additionally, more storage space is required due to the increased file size of the video when higher frame rates are used**. The AWT will be used at 817-1000 fps.**

Resolution

In general, most people would like to capture videos in as high of resolution as possible, as this allows for more detailed analysis. The resolution of an image is the number of pixels in the image and this is a factor of the resolution of the camera's sensors. Typically, the camera will limit the resolution it can achieve at higher frame rates. It is important to understand that at higher frame rates a lower resolution will be used.

The camera is only one aspect of a good video; the other key element is the lens. The actual resolution that your subject matter ends up being captured at is also a factor of the focal length of the lens. A high resolution is required when the field of view of the camera is large. When capturing high-speed videos of heart valves the field of view can be smaller but a very small spatial resolution is required to capture any finer details. To determine the minimum required camera resolution and correct focal length the minimum sensor resolution needs to be determined. This can be done by knowing the field of view and smallest feature you want to detect. A minimum of 2 pixels per smallest feature is required to accurately detect the smallest feature.

$$\text{Sensor Resolution} = \text{Image Resolution} = 2\left(\frac{\text{Field of View}}{\text{Smallest Feature}}\right)$$

For example: If the field of view of our heart valve is 200mm and you want to capture a small feature of 1mm the required sensor resolution is 400 pixels, therefore a camera with resolution of 640X480 will work.

The sensor size is the physical size of the sensor and can be determined by multiplying the sensor resolution by the pixel size on the sensor. Knowing the sensor size is useful to determine what lens the camera is compatible with. Lenses generally have fixed focal lengths. Knowing the field of view, you want to capture, along with the focal length of the camera and sensor size allows you to determine the required working distance.

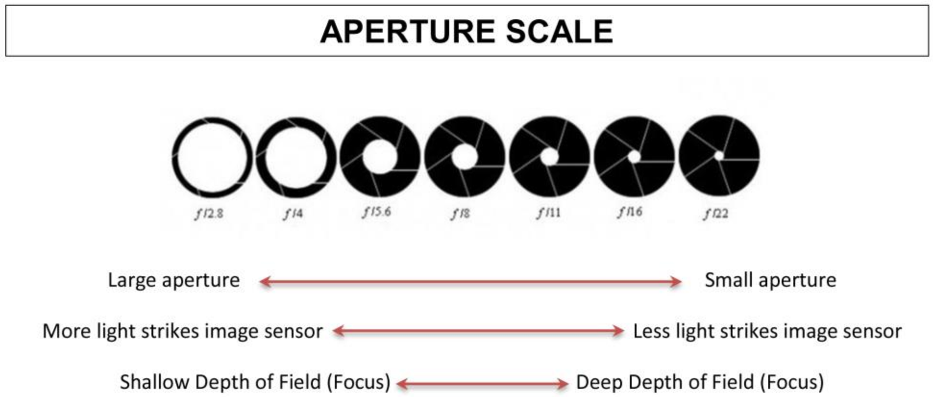
$$\text{Working Distance} = \frac{\text{Focal Length } \times \text{Field of View}}{\text{Sensor Size}}$$

It is important to understand that an increased resolution will take more storage space and often a lot of wasted data is generated. Since most valves are generally circular, cropping the frame as a square so the valve takes up most of the frame can decrease the amount of wasted resolution.

That being said, for AWT recording speeds, the resolution will typically be low at 480x480 pixels or less for a frame rate of 817+ FPS.

F-Stop/Aperture

The aperture can shrink or expand to control the amount of light let that enters the lens. The f-stop numbers are inversely related to the size of the aperture opening. The aperture also effects the depth of field of the video. Larger f-stop numbers will have a smaller aperture and therefore considerably more depth of field when focused on a subject.



When capturing high-speed videos of heart valves, the leaflet tips and belly need to be in focus at the same time, a long depth of field. **A good rule of thumb is to use an f-stop value that gives you a depth of field equal to or greater than the diameter of the valve**. Closing the aperture will also limit the light getting to the sensor so again, external lighting is required.

Using the MiDAS Lens Calculator to Specify a Lens

When using the MiDAS lens calculator (Figure 1), two main “compute” modes should be used:

- Focal Length
- Object Distance

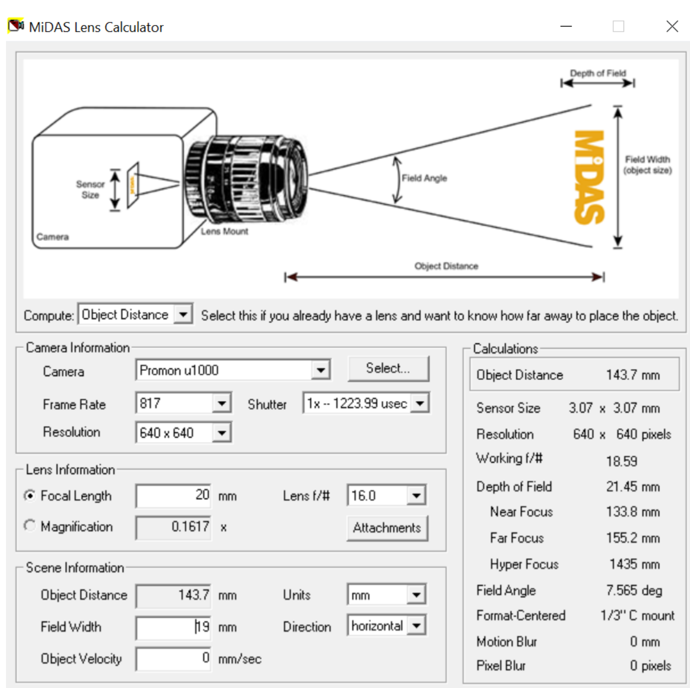


Figure 1: MiDAS Calculator

First, after defining a rough nominal object distance (see Figure 2) from the designed camera mounting system, use the MiDAS calculator to calculate focal lengths with

- The appropriate camera file (V:\Product Development_2 Active R&D Projects\1. VVL2026-AWT\Phase 0-Feasibility\Design Concepts\Camera Mount and Ring Light)
- 817 FPS
- The required f-stop value for depth of field (a higher value is usually required for smaller valves)

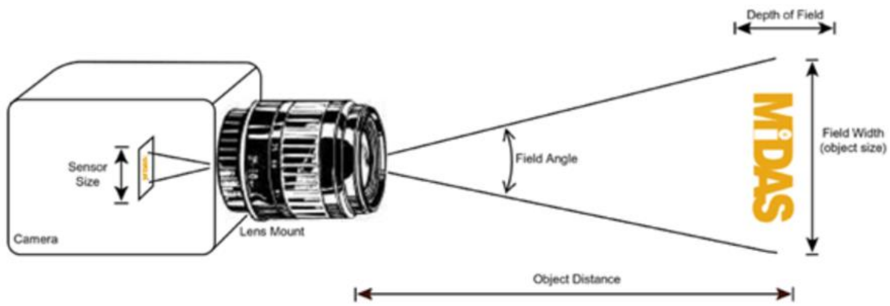


Figure 2: Camera lens calculator parameters

It is worth noting that different type of valves may require different focal length lenses, especially with mitral valves, as zoom lenses with the appropriate focal lengths are large, expensive, and hard to find.

Once you have identified a reasonable range of camera lens focal length, choose a median focal length, and ensure that it can be readily ordered. With this focal length, the object distance mode can be used to ensure that the object distance for the chosen lens works for the range of valves you expect to see and the adjustable range of the camera mounting system.

The Chosen Lens

The lens chosen for the AWT is a 20 mm focal length lens (VS-LDA20) that is relatively inexpensive and works with the original flow chamber architecture for **aortic valves** (where diameter typically ranges from 19-30 mm). This will likely work well with the new flow chamber architecture as the object distances are similar/the same.

Since lenses capable of capturing both aortic and mitral valves are both large and expensive, **a new lens specification will be needed for mitral valves** (where diameters are upwards of 55 mm). This has been determined as acceptable as most clients specialize in one type of valve (aortic or mitral).

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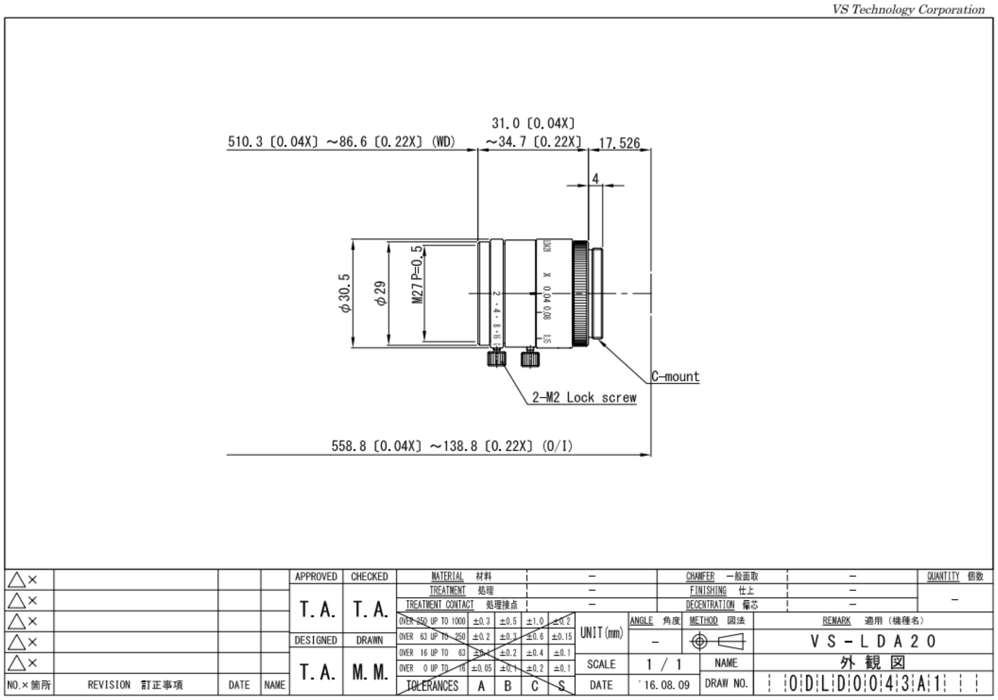

Figure 3: VS-LDA20 Drawing

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Distortionless Macro Lens

Model		VS-LDA20			
Focal Length(f)		20 mm (20.71)			
Maximum Aperture Ratio		1: 2.0			
Optical Mag. Range		× 0.04 ~ × 0.22			
Optical Mag.		× 0.04	× 0.08	× 0.15	× 0.22
FOV (V x H)	2/3″	177.5 × 210.0	88.8 × 105.0	47.3 × 56.0	32.3 × 38.2
	1/2″	120.0 × 160.0	60.0 × 80.0	32.0 × 42.7	21.8 × 29.1
	1/3″	90.0 × 120.0	45.0 × 60.0	24.0 × 32.0	16.4 × 21.8
WD		510.3 mm	251.3 mm	130.5 mm	86.6 mm
O/I (Object & Imager Distance)		558.8 mm	300.6 mm	181.3 mm	138.8 mm
Working F/# *Value at Iris Open		2.1	2.2	2.3	2.3
DOF at PCoC φ0.04mm		105.0 mm	27.5 mm	8.2 mm	3.8 mm
TV Distortion (2/3″)		-0.01 %	-0.05 %	-0.12 %	-0.17 %
Wavelength		Visible			
Mount		C-Mount			
Flange Back		17.526 mm			
Sensor Size (max.)		2/3″			
Filter Thread		M 27 P= 0.5			
Weight (approx.)		47 g			
Dimension		φ 30.5 (max.) × L = 31.0 (×0.04) ~ 34.7 (×0.22) mm			

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Figure 4: VS-LDA20 specs