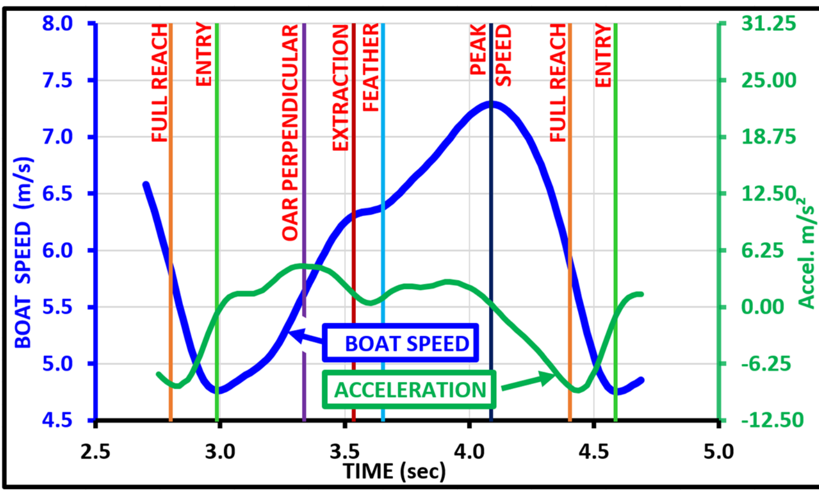
2.8 SPEED CURVE DEVELOPMENT

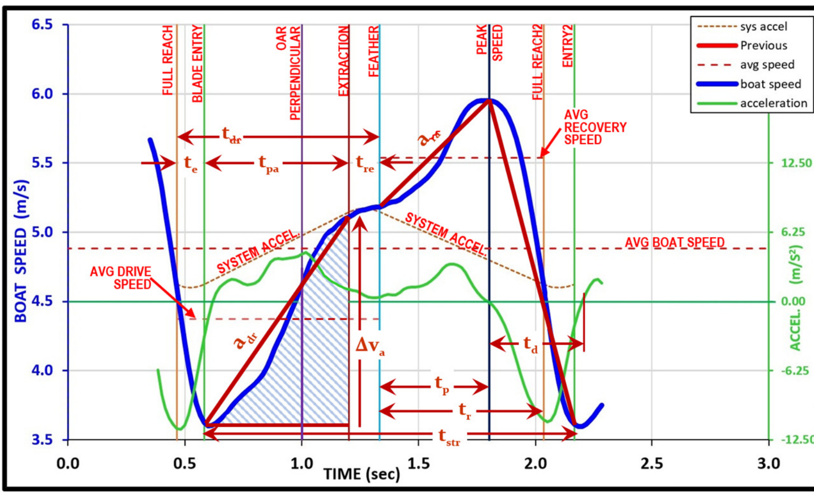
Boat speed is the only factor that determines the outcome of the race, as finish positions are determined by the average boat speed over the distance. During the stroke cycle, boat speed varies substantially. The crew accelerates the boat on the drive as they apply force with their oars. On the recovery, at racing rates, boat speed increases, then decreases as the crew moves their mass, from the finish back to catch position. The Purcerverance Boat Speed Curve (Figure 2.8a) illustrates the variation of boat speed throughout the stroke cycle. This graph links boat speed to rowing technique, with oar positions represented by vertical lines.

Figure 2.8a <u>*Purcerverance Boat Speed Curve*</u>



Dr. Kleshney, in his book The Biomechanics of Rowing (2016), notes that boat acceleration rates can provide insight into the effectiveness of the crew's rowing technique. The Purcerverance Boat Speed Curve shows boat speed in metres per second on the left (y) axis, while the right (y) axis provides a scale for boat acceleration (m/s2). Vertical lines represent the technique positions of full reach, entry, oar perpendicular (to the boat), blade extraction, feather, full reach2 and entry2 to complete the stroke cycle. A vertical line indicating the boat's peak speed serves as a data point for further analysis or for evaluating rowing technique. The horizontal (x) axis of the graph represents time and links boat speed and acceleration with the technique positions. The Purcerverance Boat Speed Curve can provide objective values for rowing technique based on speed, acceleration, or time. Figure 2.8b Curve Analysis Math shows many of the objective values that can be extracted from the data.

Figure 2.8b *Curve Analysis Math*



Rowing technique analysis based on boat speed will help coaches review biomechanics and bladework. Objective values for parts of the stroke are known as technique factors, and allow coaches to identify and focus on specific opportunities to improve crew performance. The technique factor's objective values can be compared with the crew's previous values or with the top crew's values to set improvement goals. The technique factor values allow coaches to target specific opportunities; however, they do not provide guidance related to the biomechanical (technique) changes required. Section 2.9 Objective Analysis will review technique factors and how values are calculated.

This section outlines the capture of video and the extraction of data to develop boat speed curves and identify the oar positions (technique) needed to objectively analyze rowing technique.

2.8.1 Camera Setup and Video Capture

Capturing video for speed curve development is the first step in the process and can be done with video cameras or smartphones. Simple video capture allows coaches to view rowing technique. More advanced analysis requires specific setups for recording on a camera or smartphone. The camera can be set up stationary, on land or in a vehicle (coachboat or car), moving at a constant speed, parallel to the shell and pointed perpendicular to the shell's path, as shown in Figures 2.8.1a On-Land Camera Setup and 2.8.1b Camera Setup (Boat or Vehicle).

The camera settings and setup are critical to video quality. The video file format must be compatible with the video analysis software. The video must provide a clear image, and the file size should be manageable for transfer.

The following outline will review the camera setup to maximize video recording quality. The on-land camera setup includes the sections below, **A** and **B**. For a moving camera setup, include **A** and **C**.

A. Smartphone/Camera Settings:

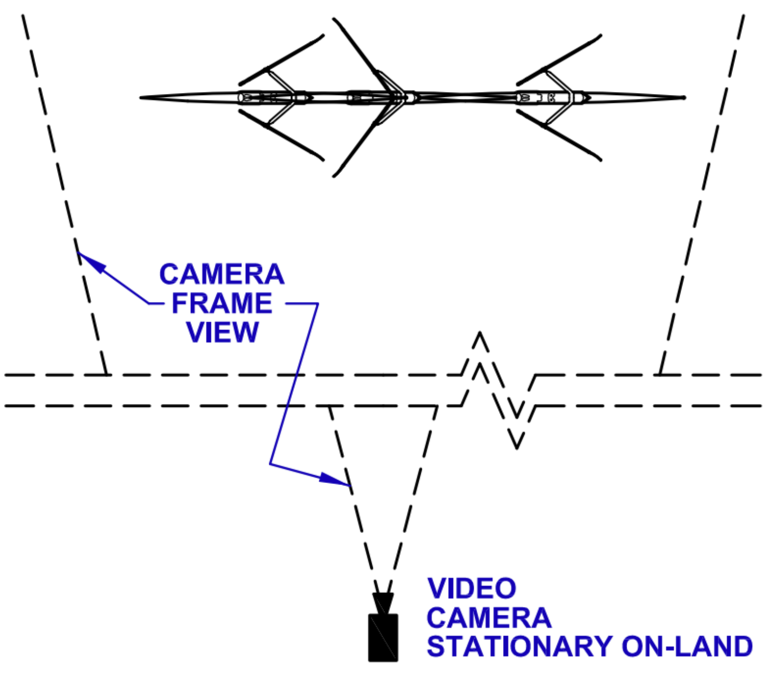
1 ☐ Set the camera to record 60 frames per second (FPS).
2 ☐ Ensure the camera stabilization setting is 'on'.
3 ☐ Angle the camera up or down to ensure the shell is in the middle of the viewfinder.
4 ☐ Aim the smartphone perpendicular to the path of the shell.
5 ☐ Video on bright days with the sun behind the camera.
6 ☐ Place a bow maker on the shell (for tracking).

The first six camera settings are required for both on-land and on-water camera setups.

B. ON-LAND Stationary Camera Setup

7 ☐ Set the smartphone about 50 meters from the shell's path
8 ☐ Connect or hold the smartphone completely stationary using a support (tripod, chair, boat stretcher).
9 ☐ Zoom camera in or out to record two full strokes, including three catches.
10 ☐ Watch this YouTube video! https://www.youtube.com/watch?v=JGeZkvKpAfo

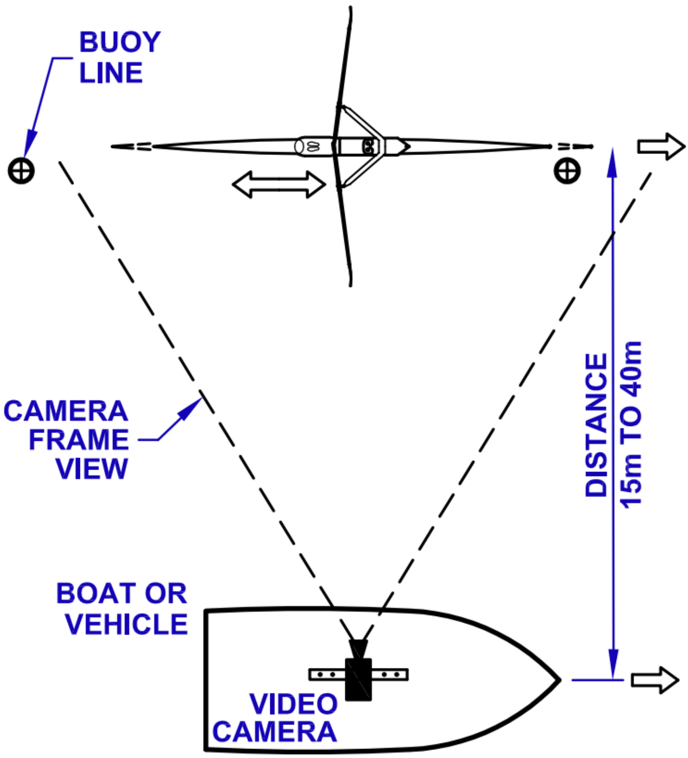
Figure 2.8.1a *Camera Setup on Land*



C. MOVING Camera Setup in Boat or Car

7 ☐ The camera must be held stationary in the coach boat or vehicle and aimed perpendicular to the shell.
8 ☐ The entire shell must be near the middle of the camera frame. Zoom in to maximize the boat.

Figure 2.8.1b *Camera Setup on Boat or Car*



9 ☐ The coach boat must be on relatively calm water, travelling parallel and at constant speed beside the middle of the shell, near the oarlock pins.

10 ☐ The coach boat should be a minimum of 15m from a single shell, 25m for an eight.

11 ☐ The shell must be travelling along (on top) a buoy line (buoy captured in the video) that will be used for movement reference.

12 ☐ Record a minimum of six strokes, and the video should be a maximum of twenty seconds in length.

The camera settings listed above are critical for high-quality video capture and analysis. A checkbox list ensures that all settings are ready before video capture.

2.8.2 Video Analysis Software

Boat speed can be derived from a video recording captured from a controlled camera setup. Software that can track image movement within the video, such as Dartfish or Kinovea, can be used to identify the boat's speed during playback. This software can measure distance in the video using a reference at the same depth (distance from the camera) in the frame. By tracking a part of the boat, such as the bow marker, frame by frame, the measured distance and the frames-per-second (FPS) time yield the boat's speed. The interval speed of the boat from frame-to-frame provides the speed curve data that serves as the basis for analysis.

Once the video has been captured and downloaded to a computer, use video analysis software that has the following capabilities:

1. Video frame stop action
2. Frame-by-frame movement backward and forward
3. Time tracking shows one one-hundredth of a second
4. Frame zoom capability
5. Drawing tools (to draw lines on video for reference)
6. Image tracking that provides distance and speed.
7. Measuring tool to assess distances

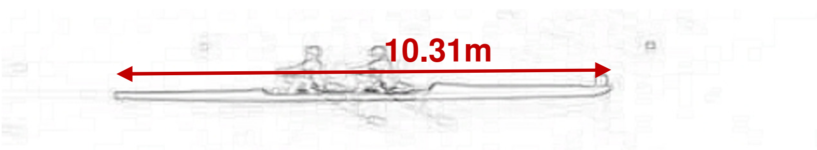
Measuring distance in the video requires an object of known length in the frame at the same distance from the camera to serve as a reference. The boat's length is the reference measurement and should be taken with the boat in the middle of the frame to minimize parallax error. Likewise, the blade's width can serve as a reference for measuring the blade slip distance from entry to extraction. Distance measurements and identification of individual frame times for various oar/blade positions provide additional data for analysis.

2.8.3 Boat Speed Identification

Video captured from a controlled camera setup, as outlined in Section 2.8.1 Camera Setup and Video Capture, can be used with video-tracking software to determine boat speed. Software that tracks the movement of specific images within a video enables advanced analysis. Software such as Dartfish or Kinovea can track boat speed.

The video software requires a reference dimension to measure distances on the video. The reference dimension is typically the length of the shell, a known length that is at the same distance from the camera as the tracking movement. Figure 2.8.3a Boat Length in Videoshows a line drawn on the shell from bow to stern and designated as the boat's length.

Figure 2.8.3a *Boat Length in Video*



The video analysis software allows a tracking marker to be placed on the edge of the bow marker, as shown in Figure 2.8.3b Tracking Marker. The marker follows coloured pixels in the video and moves with them frame by frame as the software records the distance and time. The software uses the reference dimension to determine the distance the marker moves between video frames. A summary of the distances moved each frame can be extracted from the video software.

Figure 2.8.3b *Tracking Marker*

The video file must be set up to capture an entire stroke, with additional tracking before the first catch and after the second catch. Play the video to a position where the crew is on the recovery and the oars are perpendicular to the boat, then set the ‘que in’ point for the tracking. Forward the video and set the end of the tracking, which is the ‘que out’ point after the second catch, when the oars are on the drive and perpendicular to the boat.

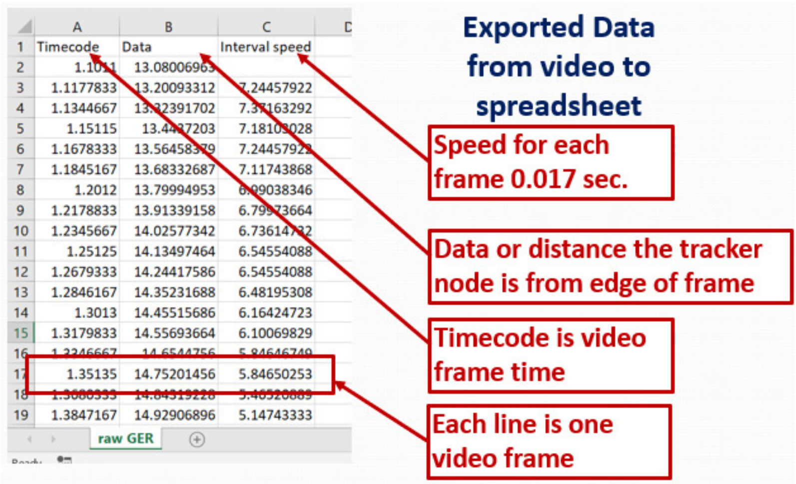
Ensure the tracking marker is set to measure and record the data in meters. If you are using Dartfish software, you need to connect the tracking marker to a data capture table. Play the video from que-in to que-out, allowing the tracking marker to follow the bow marker, and capture the movement data. The data can typically be extracted from the software by exporting it to a .txt or .csv file.

Step to Measure Boat Speed in Video

1) Open the video file in the tracking software program.
2) With the boat in the middle of the frame, place the reference dimension on the shell from bow to stern and designate the line the length of the boat.
3) Set the que-in point before the first catch and the que-out point after the second catch.
4) With the video at the que-in position, set the tracking maker on the bow marker
5) Ensure the time, movement and speed of the tracking marker data is captured
6) Play the video (lower speed) to capture the tracking marker movement data
7) Export the data from the software to a .txt or .csv file.

Figure 2.8.3c Tracking Data (csv) is a .csv file exported from the video analysis software showing Time, Distance, and Speed of the tracking marker.

Figure 2.8.3c *Tracking Data (csv)*



	A	B	C
1	Timecode	Data	Interval speed
2	1.1011	13.08006963	
3	1.1177833	13.20093312	7.24457922
4	1.1344667	13.32391702	7.37163292
5	1.15115	13.4427203	7.18103028
6	1.1678333	13.56458379	7.24457922
7	1.1845167	13.68332687	7.11743868
8	1.2012	13.79994953	6.99038346
9	1.2178833	13.91339158	6.79973664
10	1.2345667	14.02577342	6.73614732
11	1.25125	14.13497464	6.54554088
12	1.2679333	14.24417586	6.54554088
13	1.2846167	14.35231688	6.48195308
14	1.3013	14.45515686	6.16424723
15	1.3179833	14.55693664	6.10069829
16	[illegible]	[illegible]	[illegible]
17	1.35135	14.75201456	5.84650253
18	[illegible]	[illegible]	[illegible]
19	1.3847167	14.92906896	5.14743333

Boat speed data extracted from a camera captured from a moving vehicle includes both negative and positive boat speeds.

Using Microsoft Excel, boat movement data extracted from the video can be used to produce a boat speed curve. The video, captured at 60 frames per second (FPS), typically yields inconsistent data due to the high data-collection frequency (0.01667 seconds), the boat's distance from the camera, and the video quality. Graphing the raw data in an Excel spreadsheet using a scatter plot of time and interval speed produces a jagged outline of boat speed, as illustrated in Figure 2.8.3d Raw Data Boat Speed.

Boat speed does not vary instantaneously, as shown in Figure 2.8.3d (Raw Data Boat Speed). A smoothing factor spreadsheet is required to determine the actual curve. To transform the raw data into a more accurate representation of boat speed, a spreadsheet is used to average the interval speeds. Figure 2.8.3e (Raw Smoothing Calculations) shows the smoothing spreadsheet. Below the spreadsheet, the cell formulas are listed to provide the detailed calculations used to smooth the curve. The first three columns include the raw data copied from the raw data file exported from the video analysis software.

Figure 2.8.3d *Raw Data Boat Speed*

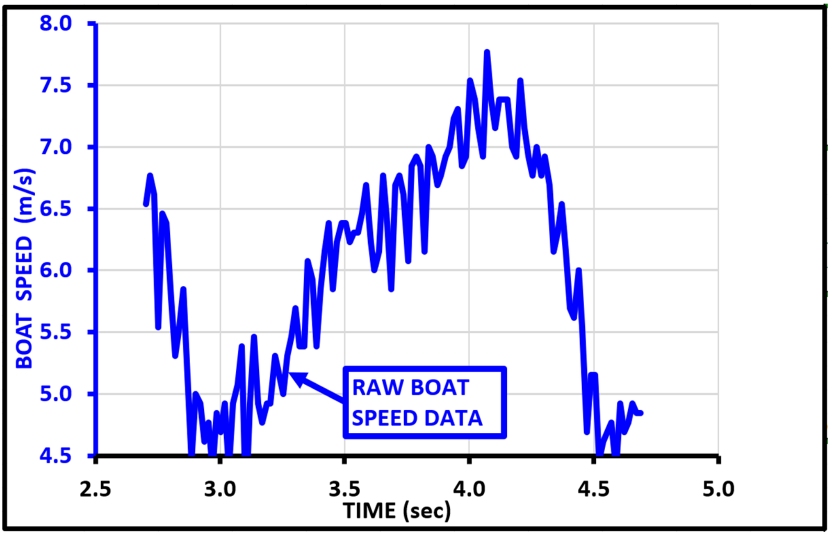


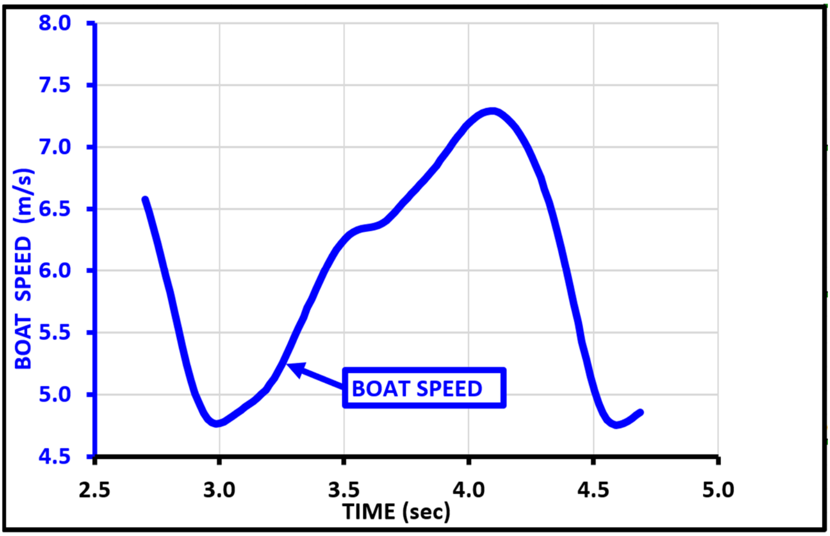
Figure 2.8.3e *Data Smoothing Calculations*

	A	B	C	D	E	F	G	H	I
1	raw data			speed smoothing			curve data		
2	Timecode	Data	Interval speed	Avg <2:>2	avg <1:>1	avg <1:>1	Timecode	Data	Interval speed
3	1.2178833	4.58892563					1.218		
4	1.2345667	4.68513814	5.76696052				1.235		
5	1.25125	4.77516556	5.39625969				1.251		
6	1.2679333	4.87893762	6.22011613	5.6846			1.268		
7	1.2846167	4.98064799	6.09650112	5.7155	5.8082		1.285		
8	1.3013	5.07204987	5.47864534	6.0244	5.8494	5.8311	1.301		
9	1.3179833	5.16826238	5.76699509	5.8082	5.8356	5.8253	1.318	0.099	5.818
10	1.3346667	5.26859828	6.01411597	5.6743	5.7910	5.7967	1.335	0.198	5.793
11	1.35135	5.3627491	5.64341662	5.8906	5.7636	5.7578	1.351	0.290	5.757
12	1.3680333	5.45964884	5.80818791	5.7258	5.7189	5.7178	1.368	0.388	5.715
13	1.3847167	5.55929751	5.9729234	5.5404	5.6709	5.6697	1.385	0.484	5.664
14	1.4014	5.64726323	5.27268122	5.7464	5.6194	5.6045	1.401	0.574	5.595
15	1.4180833	5.73797788	5.43745251	5.5713	5.5233	5.5107	1.418	0.669	5.505
16	1.4347667	5.83419039	5.76696052	5.2521	5.3894	5.3985	1.435	0.761	5.397
17	1.45145	5.92215611	5.27268122	5.3448	5.2830	5.2807	1.451	0.847	5.280
18	1.4681333	6.00599844	5.02552429	5.2521	5.1697	5.1605	1.468	0.935	5.158
19	1.4848167	6.09190247	5.1490719	4.9122	5.0289	5.0324	1.485	1.022	5.025
20	1.5015	6.17230864	4.81956018	4.9225	4.8985	4.8825	1.502	1.106	4.878
21	1.5181833	6.24790418	4.53121043	4.8607	4.7200	4.7177	1.518	1.183	4.717
22	1.5348667	6.33105928	4.98430159	4.3767	4.5346	4.5518	1.535	1.262	4.557
23	1.55155	6.40596759	4.49001761	4.3664	4.4008	4.4008	1.552	1.338	4.399
24	1.5682333	6.46713125	3.66616116	4.4591	4.2669	4.2440	1.568	1.407	4.236
25	1.5849167	6.5386034	4.28402782	3.9751	4.0643	4.0621	1.585	1.478	4.064
26	1.6016	6.60663939	4.07808938	3.7588	3.8550	3.8858	1.602	1.545	3.899
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

A) Raw data video frame time
B) Raw data track marker movement
C) Raw data interval speed of tracking marker
D) Calculation [=ABS(AVERAGE (C18,C19,C21,C22))]
E) Calculation [=AVERAGE (D19:D21)]
F) Calculation [=AVERAGE (E19:E21)]
G) Calculation [=ROUND (A20,3)]
H) Calculation [=(G20-G19)*(I19+I20)/2+H19]
I) Calculation [=AVERAGE (F19:F21)]

The smoothing spreadsheet averages point data over five video frames. At a video capture rate of 60 FPS, the data averages over 0.083 seconds to provide a more accurate representation of the boat's speed variation. Figure 2.8.3f Boat Speed curve is an Excel scatter graph of the boat's speed.

Figure 2.8.3f *Boat Speed Curve*



Along with boat speed, acceleration can be determined by calculating the change in speed over time. Acceleration is measured in meters per second per second (m/s2). The green line on the graph represents boat acceleration, and it is referenced on the right vertical axis. Acceleration is typically measured for parts of the stroke, for example, from entry to extraction. This example is a technique factor.

The speed curve data can be used to calculate the boat's acceleration during the stroke cycle. Acceleration is the change in speed divided by the change in time. Both time and speed at each interval are data points, and the Excel spreadsheet can be expanded to calculate boat acceleration, as shown in Figure 2.8.3g Calculate Acceleration.

Figure 2.8.3g *Calculate Acceleration*

	)	E	F	G	H	I	J	K
1	SPEED DATA SMOOTHING			CURVE DATA			ACCELERATION	
2	:2:>2	avg <1:>1	avg <1:>1	Timecode	Data	Interval speed	CALCULATION	AVERGAE
16	521	5.3894	5.3985	1.435	0.761	5.397	-6.1774	-6.2143
17	148	5.2830	5.2807	1.451	0.847	5.280	-7.2230	-6.8949
18	521	5.1697	5.1605	1.468	0.935	5.158	-7.2843	-7.4658
19	122	5.0289	5.0324	1.485	1.022	5.025	-7.8900	-7.9374
20	225	4.8985	4.8825	1.502	1.106	4.878	-8.6379	-8.7619
21	507	4.7200	4.7177	1.518	1.183	4.717	-9.7579	-9.2605
22	767	4.5346	4.5518	1.535	1.262	4.557	-9.3858	-9.5297
23	564	4.4008	4.4008	1.552	1.338	4.399	-9.4456	-9.6993
24	591	4.2669	4.2440	1.568	1.407	4.236	-10.2664	-9.8364
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

J) Calculation
[=(AVG(I19:I21)-AVG(I18:I20))/(G20-G19)]

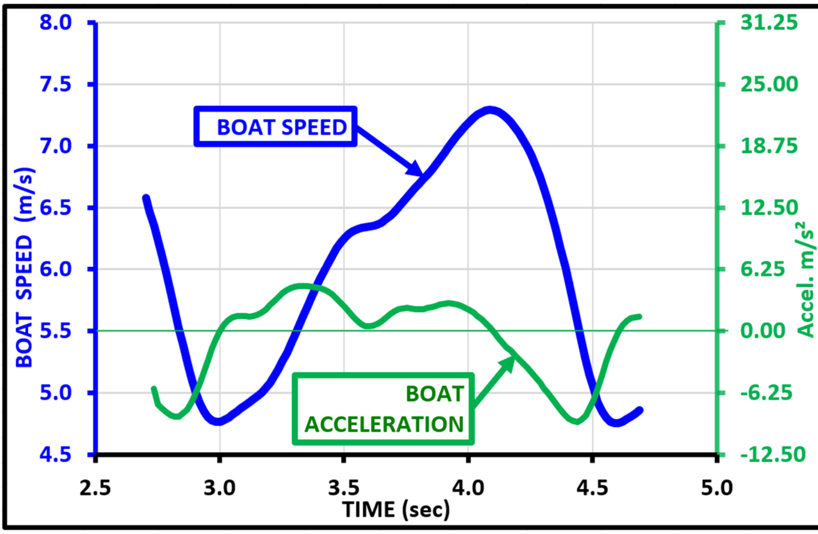
K) Calculation [=AVERAGE(J19:J21)]

The formulas that calculate boat acceleration provide the data required to develop an Excel scatter graph curve. The curve can be on the same graph as the boat speed; however, because acceleration is in m/s^2 and boat speed is in m/s, a Secondary (y) Axis is required. The horizontal (x) axis is time and will match the speed curve.

Figure 2.8.3h Boat Acceleration Curve shows the boat's acceleration plotted alongside the boat speed curve. The acceleration curve is plotted against time on the horizontal (x) axis and against acceleration on the vertical (y) axis.

The secondary acceleration axis on the right is in metres per second squared (m/s^2).

Figure 2.8.3h *Boat Acceleration Curve*



The acceleration axis values include both positive and negative values as the shell increases and decreases speed through the stroke. Zero acceleration or constant speed is highlighted as a horizontal green line on the graph.

2.8.4 Technique Positions Identification

Rowing technique analysis based on boat speed provides objective insight into effective rowing technique. Analyzing rowing technique based on boat speed requires that rowing technique and speed be linked. The athlete's position and the oar's position throughout the stroke can identify the phases of the stroke cycle. There are typically seven oar positions that mark the catch, drive (power application), extraction and recovery phases. These seven positions allow the measurement and calculation of technique analysis factors. The oar positions include:

1. **Full reach**, when the athlete is at full reach, oar at catch angle

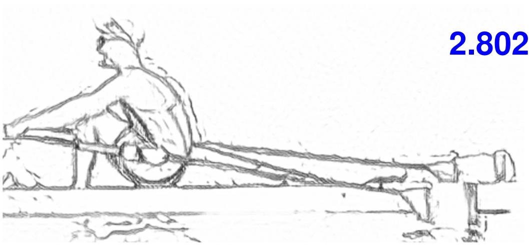
2. **Blade entry**, when the blade becomes completely buried
3. **Oar perpendicular** to the boat: when the oar reaches perpendicular to the boat on drive
4. **Blade extraction** occurs when the blade tip stops moving in a direction opposite to the boat
5. **Blade feather**: when the blade reaches the feather position and the athlete is in the finish position, the oar at the finish angle
6. **Full reach 2**, similar to (1) Full reach
7. **Blade entry 2**, similar to (2) Blade entry

To identify the oar positions, open the video file in the analysis software. The analysis software typically displays the video frame time in milliseconds (1/1000th of a second). Use the frame-by-frame advance tool to move the video to specific oar positions and record the frame time associated with each oar position. These oar positions must be from the same stroke during which boat speed was captured. The following sections detail and describe the seven specific oar positions related to technique:

2.8.4.1 Full Reach Frame Time

The first position of the oar to identify by time is when the athlete is in the full reach position at the catch. At this point, the oar is at the catch angle. Typically, at full reach, top-level athletes have their blades very close to the water's surface as shown in Figure 2.8.4.1a Full Reach.

Figure 2.8.4.1a. *Full Reach*



This position is sometimes difficult to identify on the video because the athlete's body appears to remain in the same position for several video frames. If no body movement towards the bow is identifiable, the frame before the blades touch the water will show the athlete in the full reach position. Record the video frame time at which the athlete is in the full reach position.

2.8.4.2 Blade Entry Frame Time

The second position of the oar to identify is the entry, when the blade becomes fully buried. This position is typically easy to find by moving the video frame-by-frame forward and backward to determine when the blade is fully covered. At times, it may be challenging to decide between two frames due to water splash, and referencing the oar shaft angle into the water may help identify the correct frame. Record the time of the frame as the blade entry time.

Figure 2.8.4.2a. *Entry*

Identifying the Blade Entry time for crew boats may be difficult if their entry timings are not synchronized. The time determined for a crew boat is the average time of the blades at full bury. Moving the video back and forth will allow identification of the time for multiple blades. Average the times to identify the frame time most applicable to the crew.

2.8.4.3 Oar Perpendicular Frame Time

The oar's perpendicular position in time is indicated when the oar shaft is perpendicular to the boat. The frame time identifies the stroke position. The video can be played frame-by-frame to determine when the oar is in the perpendicular position. If the oar is not near the centre of the video frame when perpendicular, it may be challenging to identify the correct frame. Note on the analysis sheet that the time at perpendicular is only estimated.

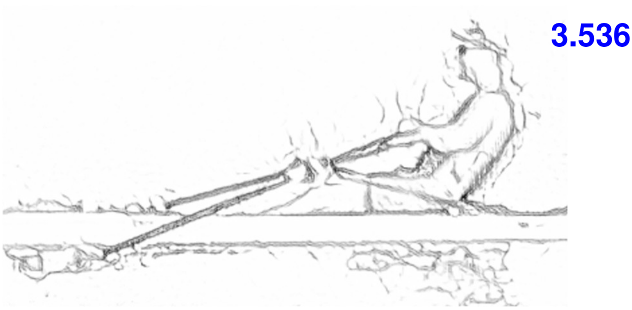
Figure 2.8.4.3a. *Oar Perpendicular*

In crew boats, it is hard to determine the time if oars do not reach the perpendicular in the same frame. Review the estimated time for each oar and use the average as the identity perpendicular. Record the time.

2.8.4.4 Blade Extraction Frame Time

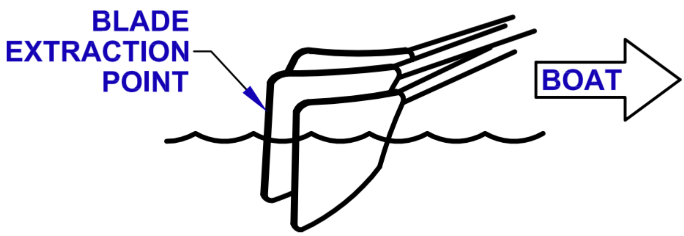
The release phase begins with the blade's extraction at the end of the late drive phase of the stroke, as shown in Figure 2.8.4.4a Blade Extraction.

Figure 2.8.4.4a *Blade Extraction*



During the late drive, the oar rotates towards the stern of the boat. The extraction point is identified when the blade begins to move horizontally in the same direction as the boat. This typically occurs when the blade is half out of the water. At that point, the oar no longer acts as a lever to apply force on the oarlock. Record the extraction point time. Figure 2.8.4.4a, Blade Extraction Point, shows the position of the blade in three successive video frames and identifies the blade extraction point.

Figure 2.8.4.4b *Blade Extraction Point*

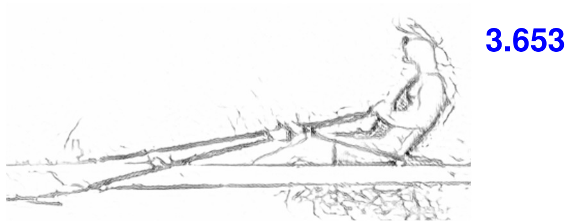


The blade extraction point time is the video frame before the blade starts to move in the same direction as the boat. Record the time of the frame. Again, record the average extraction time for a crew boat on the Technique Analysis Record Chart, Figure 3.10.12a.

2.8.4.5 Blade Feather Frame Time

The point in the stroke the blade becomes fully feathered is the finish position as shown in Figure 2.8.4.5a Finish position.

Figure 2.8.4.5a *Finish Position*



In the finish position the athlete is sitting closest to the bow, and the oar is at the finish angle. The feather time is the frame time the blades first reach the feather position. In crew boats with poor timing, use the average frame time. Record the feather time.

2.8.4.6 Full Reach 2 Frame Time

As with the first Full Reach position, the frame time for Full Reach 2 must be identified. Review Figure 2.8.4.1a Full Reach for details. Record the time. In the example curve, the full reach 2 video frame time is 4.404.

2.8.4.7 Blade Entry 2 Frame Time

Blade Entry 2 is similar to the first Blade Entry time and blade position identified in Figure 2.8.4.2a Blade Entry. The stroke rate is calculated from the total time of one complete stroke cycle, which is Entry 2 time minus Entry 1 time. Record the Blade Entry 2. In this example, it is 4.587.

2.8.5 Boat Speed Spreadsheet

The position of the athlete and oar throughout the stroke has been identified by time within the same stroke that generated the boat speed curve. When all the oar position points (video frame times) are known, they can be inserted into the spreadsheet individually.

Figure 2.8.5a Oar Position Data is a table in an Excel file that provides the data for the vertical lines on the graph that indicate the oar positions. This data can be inserted into the graph by clicking the boat speed graph, selecting Chart Design, then selecting Data, which opens the Select Data Source dialogue box. Select Add to enter the oar position (technique) points. These data lines must be referenced to the primary left (speed) axis. The coordinates in the table below provide the x and y limits of the line.

Figure 2.8.5a *Oar Position Data*

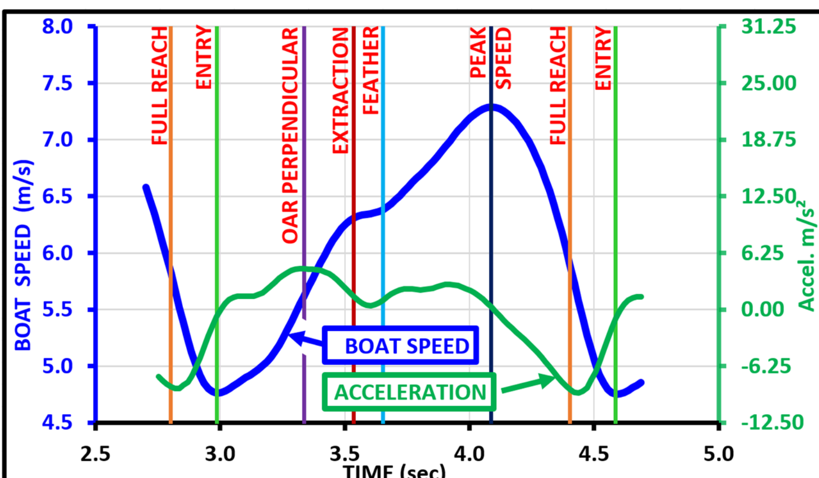
oar position	line		oar position	line	
full reach (x)	2.802	2.802	feather (x)	3.653	3.653
full reach (y)	10	0	feather (y)	10	0
entry (x)	2.986	2.986	entry2 (x)	4.404	4.404
entry (y)	10	0	entry2 (y)	10	0
perpendicular (x)	3.336	3.336	full reach 2 (x)	4.587	4.587
perpendicular (y)	10	0	full reach 2 (y)	10	0
extraction (x)	3.536	3.536			
extraction (y)	10	0			

These data points (times) will also be used for technique factor calculations discussed in Section 2.9 Objective Analysis. Once the data is added to the spreadsheet, the end result is Figure 2.8.6a Speed Curve Racing.

2.8.6 Boat Speed Curves

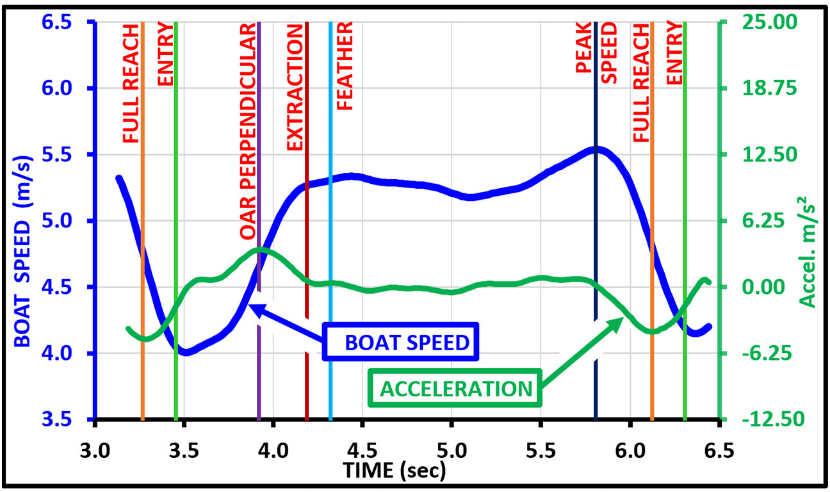
Figure 2.8.6a Speed Curve Racing is the combination of boat speed, acceleration and oar position data referenced by time.

Figure 2.8.6a *Speed Curve Racing*



During practices at lower rates and intensities, the duration of the drive and recovery may be significantly different from those in racing. The intensity of the power application during the drive will vary considerably depending on the assigned workout intensity. The duration of recovery also varies with stroke rate, and at low rates it can be two to four times longer than in racing.

Figure 2.8.6b *Speed Curve Practice*



The practice curve can show the relationship between the movements of the rowing technique at race rate and at practice rate. This comparison can help coaches identify opportunities to improve rowing technique that lead to increases in boat speed.

The boat speed curve is a visual representation of the rowing stroke that links speed and technique. Section 2.9, Objective Analysis, provides an overview of technique factors, their calculations, and typical values.