2.9 OBJECTIVE ANALYSIS *by Mike Purcer*

Analyzing rowing technique helps coaches identify specific areas for improving crew performance. Coaches have used film and video to observe athletes' biomechanical movements in slow motion. They have also employed various sensors on boats and oars to obtain objective measurements of motion, including acceleration, angles, and forces. Dr. Valery Kleshnev, in his book The Biomechanics of Rowing (2016), states that boat acceleration can be a useful diagnostic tool for assessing different aspects of rowing technique. Analyzing rowing technique using objective measurements of boat acceleration, speed, or time can provide coaches with valuable insights into effective rowing and strategies to enhance performance. This section introduces technique factors that can be measured to provide coaches with objective metrics related to performance.

Monitoring changes in boat speed throughout the stroke and linking them to body and oar positions provides measurable data on rowing technique and its relationship to speed. The link between technique and boat speed provides an objective means of assessing how the crew's rowing technique affects speed. An objective analysis of rowing technique can give coaches tangible feedback on crew performance.

The technique factor's objective values can be compared with the crew's previous values or with those of top crews in their boat class to assess performance. These values allow coaches to identify specific opportunities for improvement.

This section presents data from video recordings of crews at the World Championships between 2017 and 2023. The author's footage of crews in the A and B finals was recorded near the 1200-metre mark of the races. The analysis covers one stroke from each crew. Measurement analysis, like all measurement processes, involves an unknown error factor. These factors are also influenced by environmental conditions. For example, acceleration rates may be affected by tailwinds or headwinds. The author examined various boat classes at the World Championships and correlated factor values with performance (finish position). The results are inconclusive, as no single factor can be isolated, and all factors influence performance.

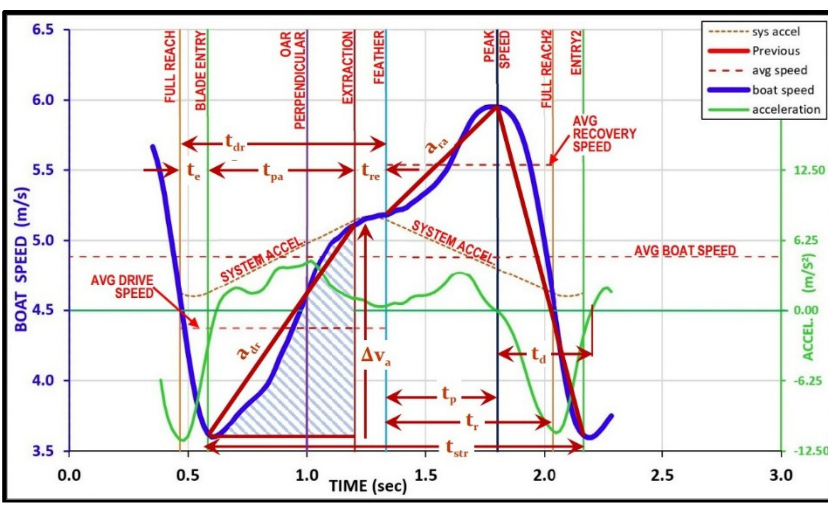
There are five steps for objectively analyzing rowing technique based on boat speed.

1) Video capture
2) Boat speed identification
3) Rowing technique position identification
4) Boat speed/acceleration data development
5) Technique factor analysis

The first requirement is that the crew must be captured on video. Second, the boat's speed must be extracted from the video, and a speed curve and a mathematical analysis must be performed. Finally, the factor values must be analyzed in relation to the norms for the athlete category and boat class.

Speed Curve Analysis, Figure 2.9a shows a boat speed curve and some of the calculated factors.

Figure 2.9a *Speed Curve Analysis*



Technique Factors

Speed curve analysis helps coaches and athletes see the boat's speed and acceleration in relation to rowing technique. Technique factor values provide objective data and link rowing technique to boat speed. Figure 2.9b, Technique Factors, lists seven aspects that provide objective values, as described in this section.

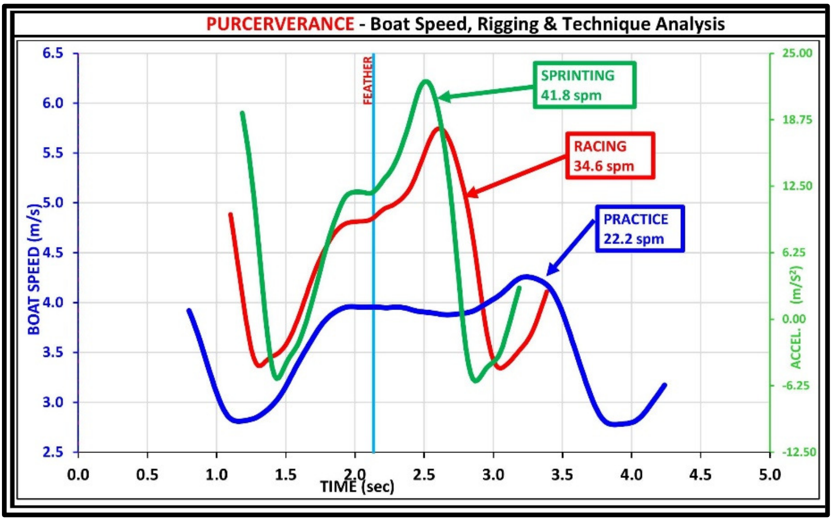
Figure 2.9b *Technique Factors*

Section	Technique Factor	page
2.9.1	Entry Time	319
2.9.2	Drive Hump	322
2.9.3	Drive Acceleration	325
2.9.4	Release Time	328
2.9.5	Recovery Acceleration	331
2.9.6	Peak Boat Speed	334
2.9.7	Deceleration Time	337

The speed of rowing technique movements and the power exerted differ between racing and practice at low stroke rates. Analysis of speed curves at low rates may not reveal the same opportunities as analysis at high rates. Nonetheless, comparing both high and low rates should be done to identify and understand the differences in rowing techniques.

Rowing is a cyclical movement of continuous drive and recovery phases. During the drive (power application phase), the boat, athlete, and oars can be accelerated. During the recovery phase, the crew can accelerate the boat by transferring the momentum of their body mass by pulling the footstops to their bodies as they move from the finish position to full reach at the catch. Typically, the boat's hull speed increases throughout the stroke, except for a short time between peak boat speed on the recovery and the blade entry. The author feels that although the stroke is cyclical, the technique phases of drive and recovery should be considered separately as opportunities for boat speed.

Figure 2.9c *Practice and Racing Curves*



The question may be whether the rowing technique biomechanical movements used in practice are the same as those used at higher speeds in racing. Conversely, can we practice a different rowing technique at lower stroke rates that enhances our abilities at racing speeds? More work is needed, but objective analysis comparing low-rate practice with racing speed curves will help answer the question.

The boat speed data extracted from video, as discussed in Section 3.8 Speed Curve Development, includes:

1) video frame time
2) distance moved
3) interval speed

Figure 2.9d Boat Speed Data shows the Excel file columns of the boat speed data. This data provides the values needed to calculate the technique factor values.

Vt_{c1} = video frame time entry1 or catch1
Vt_{c2} = video frame time entry2 or catch2
Vt_{ex} = video frame time blade extraction
Vt_{fp} = video frame time feather (finish position)
Vt_{ps} = video frame time peak boat speed
Vt_{fr1} = video frame time full reach 1
Vt_{fr2} = video frame time full reach 2
Vd_{c1} = video boat distance at entry1 or catch1
Vd_{c2} = video boat distance at entry2 or catch2
Vd_{ex} = video boat distance at the extraction point
Vd_{fp} = video boat distance at feather (finish position)
Vd_{ps} = video boat distance at peak speed
Vd_{fr1} = video boat distance at full reach 1
Vd_{fr2} = video boat distance at full reach 2
Vs_{c1} = video interval boat speed at entry1 or catch1
Vs_{c2} = video interval boat speed at entry2 or catch2
Vs_{ex} = video interval boat speed at the extraction point
Vs_{fp} = video interval boat speed at feather
Vs_{ps} = video interval boat speed at peak speed
Vs_{fr1} = video interval boat speed at full reach 1
Vs_{fr2} = video interval boat speed at full reach 2

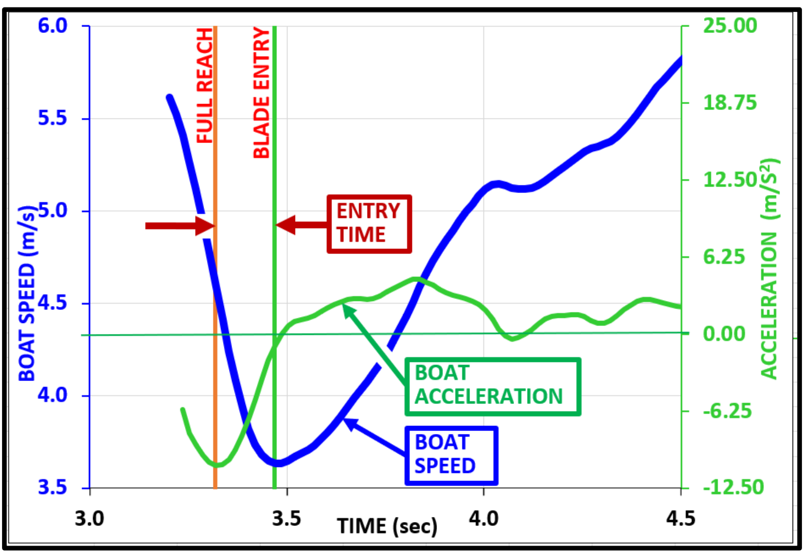
Vt_{op} = video frame time oar perpendicular (drive)
Vd_{op} = video boat distance oar perpendicular (drive)
Vs_{op} = video interval boat speed oar perpendicular (dr)

A diagram of the oar/blade positions through the stroke linked with the positions of the full reach, entry oar perpendicular, blade extraction, feather, full reach two and entry two. This paragraph may further describe the link between technique and oar positions.

2.9.1 Entry Time

Entry time is a technique factor that provides an objective measure of the movement of the catch during entry. The entry time is measured in hundredths of a second between when the athlete achieves the full reach position at the catch and the blade entry (blade full bury) point. This part of the stroke was traditionally known as the catch and is now referred to as the entry. During the entry time, the athlete lifts their hands and pushes on their footstops to immerse the oar blade underwater. The boat's speed slows through the entry time and typically does not increase until the blade is fully buried. Figure 2.9.1a Entry Time is a graph of the boat's speed (blue line) and acceleration (green line), and it identifies the full reach and entry positions as vertical lines.

Figure 2.9.1a *Entry Time*



Coaches have long considered the entry movement a unique phase of the stroke cycle and a critical part of the rowing technique. Typically, the boat transitions from negative to positive acceleration when the blades become fully buried. The quicker the blades are buried, the sooner positive boat acceleration is achieved. Reducing the time between full reach and blade entry extends the effective stroke length as the blades, buried quicker in the drive phase. The quicker entry also reduces the loss in boat speed between full reach and full bury and along wit the extended stroke length link the entry time to improved performance. Technique factors that link to improvement are known as performance factors.

The entry time is calculated from the video time data as follows:

$$\textbf{ENTRY TIME} = Vt_{c1} - Vt_{fr1}$$

where: Vt_{c1} = video time oar at entry (full bury)
Vt_{fr1} = video time oar at full reach1

The objective measurement of entry time provides the coach and crew with an evaluation of their performance. Data extracted from video taken at the World Rowing Championships is shown in Figure 2.9.1b Entry Time Singles Pairs. The graph charts entry times with performance (first through twelfth place) for singles and pairs. The graph also shows trendlines for the data related to each boat class.

Figure 2.9.1b *Entry Time Singles Pairs*

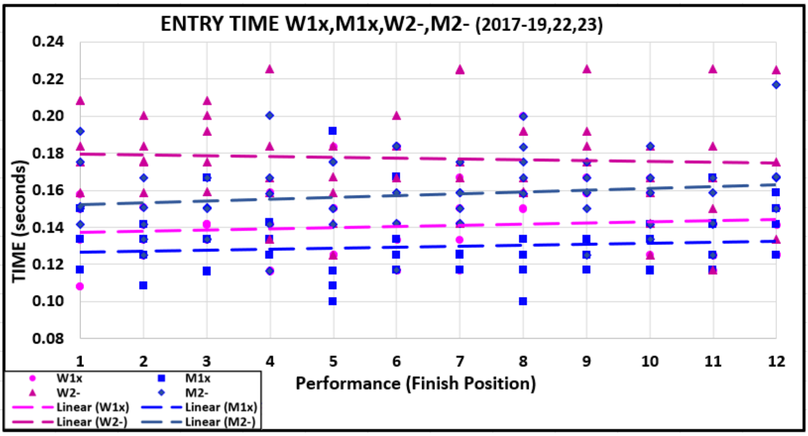


Figure 2.9.1c. Entry Time Data shows the entry times for a variety of boat classes at the World Championships. The data on the chart includes the average entry time for top crews in each boat class. The chart also includes the standard deviation, minimum and maximum entry times for each boat class, and the number of crews in the sample.

The chart also compares entry time to the entire stroke cycle time to provide the percent (%) of cycle value.

Figure 2.9.1c *Entry Time Data*

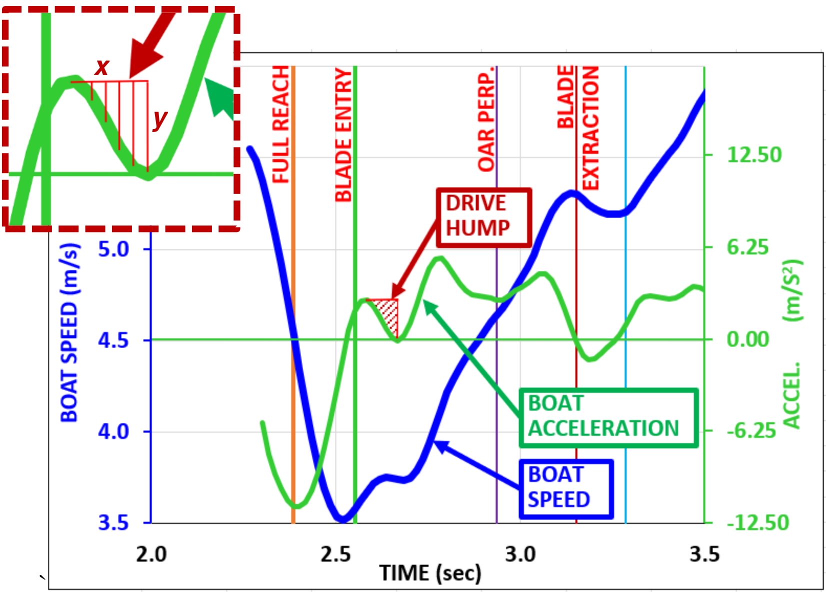
Boat Class	**Entry Time**	standard deviation	Min.	Max	**% of Cycle**	Data Reference (# of crews)
W1x	**0.14**	0.02	0.11	0.20	**8.0%**	(59) WC '17,'18,'19,'22,'23
W2x	**0.15**	0.02	0.12	0.17	**8.8%**	(16) WC '19, '22, '23
W4x	**0.15**	0.01	0.13	0.18	**9.4%**	(18) WC '17,'23
W2-	**0.18**	0.03	0.12	0.24	**10.7%**	(59) WC '17,'18,'19,'22,'23
W4-	**0.17**	0.02	0.15	0.22	**10.7%**	(18) WC '19,'23
W8+	**0.18**	0.02	0.13	0.23	**11.6%**	(40) WC '17,'18,'19,'22,'23
M1x	**0.13**	0.02	0.10	0.19	**7.8%**	(59) WC '17,'18,'19,'22,'23
M2x	**0.13**	0.01	0.11	0.16	**8.3%**	(17) WC' 19,' 22, '23
M4x	**0.15**	0.02	0.12	0.18	**9.2%**	(14) WC '17,'23
M2-	**0.16**	0.02	0.12	0.22	**10.0%**	(60) WC '17,'18,'19,'22,'23
M4-	**0.17**	0.02	0.12	0.20	**10.7%**	(18) WC '17,'19,'23
M8+	**0.17**	0.02	0.13	0.22	**11.4%**	(51) WC '17,'18,'19,'22,'23

By objectively measuring entry times, coaches can compare their crew's entries throughout the year to monitor progress. Entry times can be compared with the data in Figure 2.9.1c, and much slower times should be considered an opportunity for improvement. As entry time is designated a performance factor, coaches must continue to monitor and focus on improving this part of the stroke.

2.9.2 Drive Hump

The Drive Hump is a term first identified by Dr. Varery Kleshnev in his book The Biomechanics of Rowing to identify a reduction in boat acceleration just after the blade entry. This reduced acceleration rate is typical for many crews, and more severe values can result in a loss in boat speed (negative acceleration). Figure 2.9.2a Drive Hump shows boat speed and acceleration curves for the drive phase of the stroke on the right. To the top left, on the figure, is a detailed section of the acceleration curve highlighting the reduced acceleration part just after the entry.

Figure 2.9.2a <u>*Drive Hump*</u>



The drive hump technique factor is the calculated value for the reduced acceleration. It is the loss in acceleration (m/s^2) multiplied by the time. When acceleration slows, the curve tracks downward even though it may still be positive acceleration. Boat acceleration is calculated for each video frame and represents a point on the curve. The drive hump factor value is the sum of the losses in accelerations multiplied by time for that section. The factor value only calculates the loss in acceleration and ends once the curve starts upward (increasing acceleration).

Figure 2.9.2a, top left, shows the reduced acceleration segments for the video frame time (x) and, the loss in acceleration (y) for each frame. The loss in acceleration represents a negative value making the sum of the losses for the drive hump factor value negative.

Drive Hump = $x_1 \cdot (-y_1) + x_2 \cdot (-y_2) + x_3 \cdot (-y_3)$ ...

Where: x is the time between video frames
y is the loss in acceleration

example: x_1, x_2, x_3 = frame time (0.0167 seconds)
$y_1 = 2.425 - 2.628 = -0.203$
$y_2 = 2.112 - 2.628 = -0.516$
$y_3 = 1.854 - 2.628 = -0.774$
2.628 is the peak acceleration before the loss

The drive hump data for singles and pairs at the World Championships is shown in Figure 2.9.2b Drive Hump Singles Pairs. The vertical axis on the left is the sum of the acceleration losses multiplied by the time. The factor value is negative as all losses are negative.

Figure 2.9.2b *Drive Hump Singles Pairs*

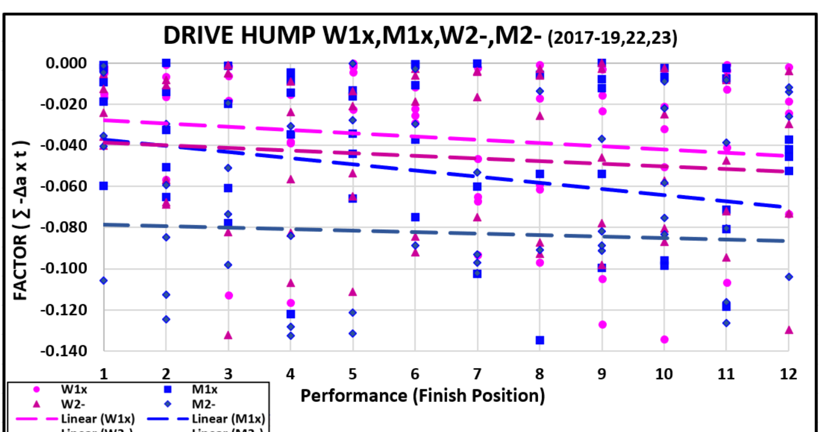


Figure 2.9.2b Drive Hump Singles Pairs includes trendlines for each of the boat classes. The data is very limited; however, the trendlines appear to suggest that the drive hump factor may be related to performance.

Figure 2.9.2c Drive Hump Data shows values for a variety of boat classes at the World Championships. The chart includes the average drive hump value for crews in each boat class. It also shows the standard deviation, minimum and maximum values for each boat class, and the number of crews in the sample.

Figure 2.9.2c *Drive Hump Data*

Boat Class	**Drive Hump**	Standard Deviation	Min.	Max	Data Reference (# of crews)
W1x	**-0.035**	0.045	-0.237	0.000	(59) WC ’17,’18,’19,’22,’23
W2x	**-0.041**	0.032	-0.107	0.000	(16) WC ’19, ’22, ‘23
W4x	**-0.031**	0.049	-0.188	0.000	(18) WC ’17,‘23
W2-	**-0.046**	0.040	-0.140	0.000	(59) WC ’17,’18,’19,’22,’23
W4-	**-0.064**	0.073	-0.213	0.000	(18) WC ’19,’23
W8+	**-0.030**	0.030	-0.106	0.000	(40) WC ’17,’18,’19,’22,’23
M1x	**-0.053**	0.055	-0.201	0.000	(59) WC ’17,’18,’19,’22,’23
M2x	**-0.057**	0.046	-0.165	0.000	(17) WC' 19,' 22, '23
M4x	**-0.041**	0.052	-0.169	0.000	(14) WC '17,’23
M2-	**-0.083**	0.059	-0.251	0.000	(60) WC ’17,’18,’19,’22,’23
M4-	**-0.071**	0.058	-0.213	0.000	(18) WC ’17,’19,’23
M8+	**-0.046**	0.051	-0.281	0.000	(51) WC ’17,’18,’19,’22,’23

The cause of the reduced boat acceleration remains unknown; however, Dr. Kleshnev has suggested four possible causes in his book (Kleshnev, 2020). 1. Disconnection of the legs and trunk, 2. Double trunk work, 3. Sinking the blade too deeply, 4. Too rapid an increase in force.

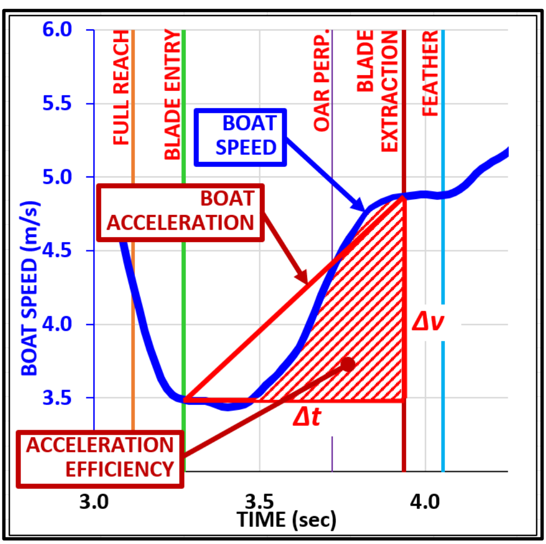
Coaches can review Section 2.1 Drive and Section 2.1.3 Early Drive for additional details on technique movements and minimizing the reduction in acceleration (drive hump) after the entry.

2.9.3 Drive Acceleration

Drive acceleration is the technique factor measuring the boat's acceleration (m/s^2) between the blade entry and the blade extraction. The acceleration is a simple calculation of the change in speed (Δv) divided by the change in time (Δt). The acceleration rate is measured as a straight line between the boat's speed at entry and extraction, which does not reflect the actual movement of the boat as it does not accelerate at a consistent rate. This technique factor provides a value that measures the crew's ability to apply power and stay connected with the blade in the water.

Figure 2.9.3a Drive Acceleration shows a boat speed curve and identifies the straight line of boat acceleration from entry to extraction.

Figure 2.9.3a *Drive Acceleration*



$$\textbf{DRIVE ACCELERATION} = \frac{(Vs_{ex} - Vs_{c1})}{(Vt_{ex} - Vt_{c1})}$$

where: Vs_{c1} = video frame interval speed catch1
Vs_{ex} = video frame interval speed blade extraction

Vt_{c1} = video frame time feather
Vt_{ex} = video frame time blade extraction

Figure 2.9.3a Drive Acceleration identifies the drive acceleration efficiency (DAE), which is the boat's movement during the power application stage, entry to extraction. The DAE is the boat's movement compared to the theoretical movement at constant acceleration, not including the initial speed. As the boat does not accelerate on a consistent basis, the DAE represents a percentage of the linear drive acceleration. The following formula compares the actual boat movement to the theoretical movement at constant acceleration.

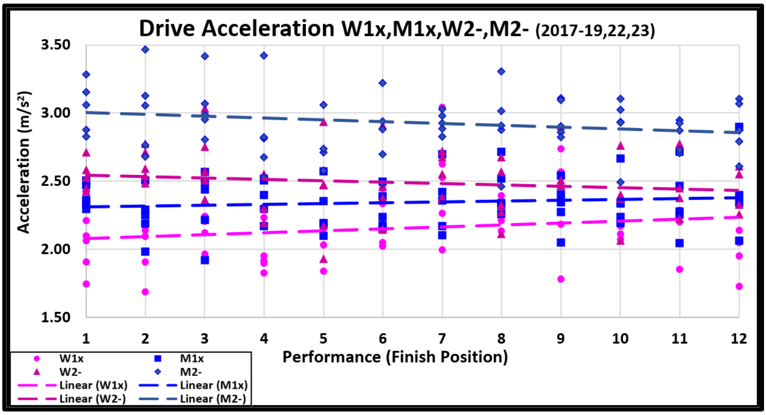
Calculation for Drive Acceleration Efficiency (DAE):

$$\mathbf{DAE} = \frac{[\,(Vd_{ex} - Vd_{c1}) - Vs_{c1} \cdot (Vt_{ex} - Vt_{c1})\,]}{[\,(Vs_{ex} - Vs_{c1}) \cdot (Vt_{ex} - Vt_{c1}) / 2\,]}$$

where: Vd_{c1} = video boat distance at catch 1
Vd_{ex} = video boat distance blade extraction
Vs_{c1} = video frame interval speed catch 1
Vs_{ex} = video frame interval speed extraction
Vt_{c1} = video frame time catch 1
Vt_{ex} = video frame time blade extraction

Drive acceleration data from singles and pairs taken at the World Championships between 2017 and 2023 is shown in Figure 2.9.3b Drive Acceleration Singles Pairs.

Figure 2.9.3b *Drive Acceleration Singles Pairs*



Crew performance of the power application stage should analyze drive acceleration, drive acceleration efficiency and boat speed change, entry to extraction. Boat speed increase between entry and extraction is a third technique factor used to evaluate the power application stage.

$$\textbf{BOAT SPEED INCREASE} = Vs_{ex} - Vs_{c1}$$

where: Vs_{ex} - video interval speed blade extraction
Vs_{f} – video interval speed catch 1

Drive acceleration is affected by the power capacity of the crew and the rigging leverage dimensions. High drive acceleration values may reflect lighter rigging loads (leverage), resulting in lower boat speed increases or reduced effective stroke lengths.

Figure 2.9.3c Drive Acceleration Data provides data from the World Championships for various boat classes.

Figure 2.9.3c *Drive Acceleration Data*

Boat Class	**Drive Accel.**	Standard Deviation	Min.	Max	**Drive Eff.**	Data Ref. (# of crews)
W1x	**2.15**	0.25	1.69	3.04	**85.9%**	(59) WC '17,'18,'19,'22,'23
W2x	**2.37**	0.22	2.01	2.77	**84.9%**	(16) WC '19, '22, '23
W4x	**2.39**	0.26	1.75	2.81	**83.0%**	(18) WC '17,'23
W2-	**2.49**	0.23	1.93	3.03	**93.4%**	(59) WC '17,'18,'19,'22,'23
W4-	**2.59**	0.22	2.22	2.93	**94.3%**	(18) WC '19,'23
W8+	**2.60**	0.30	1.94	3.14	**91.5%**	(40) WC '17,'18,'19,'22,'23
M1x	**2.35**	0.19	1.92	2.90	**81.0%**	(59) WC '17,'18,'19,'22,'23
M2x	**2.67**	0.18	2.32	2.89	**76.8%**	(17) WC' 19,' 22, '23
M4x	**2.57**	0.28	2.10	3.06	**70.0%**	(14) WC '17,'23
M2-	**2.93**	0.24	2.46	3.64	**94.1%**	(60) WC '17,'18,'19,'22,'23
M4-	**3.11**	0.26	2.54	3.42	**90.0%**	(18) WC '17,'19,'23
M8+	**3.07**	0.29	2.32	3.66	**88.5%**	(51) WC '17,'18,'19,'22,'23

The crew's only opportunity to accelerate the boat/crew system is between entry and extraction during the power application stage. During this stage, the power applied by the athlete to the oar handles is used to a) accelerate the boat, b) accelerate the athlete's center of mass (COM), and c) overcome resistance. The movement of the athlete's COM is greater than the boat's as the athlete travels a greater distance during the drive. While the boat moves from point A to B during the drive phase, the athlete moves with the boat, and their COM also moves within the boat the distance from the catch position to the finish position. The athlete's COM movement during the drive requires part of the athlete's applied force, resulting in reduced boat acceleration. However, the force used results in a new location of the athlete's COM (finish position) within the boat. The new COM location is potential momentum that can be used during the recovery to accelerate the boat.

During the recovery, the athlete pulls their footstops toward their COM, transferring their momentum (inertia) and increasing the boat's speed at racing rates. The movement of the athlete's COM during the rowing stroke cycle is critical to effective rowing technique. Coaches must understand how the athlete's COM movements, affect performance not only on the recovery but also on the drive.

The drive acceleration efficiency factor provides a comparative value that provides insight into the drive acceleration factor value. Higher acceleration rates with lower DAE will limit the distance the boat moves and the average drive speed during the power application stage.

The average boat speed on the drive compared to the average boat speed for the full stroke cycle reflects the ability of the crew to effectively transfer power on the oar handles. The following calculations will provide the value for the DSPBS.

Average drive speed (ADS)

$$\mathbf{ADS} = (Vd_{fp} - Vd_{fr1}) \;/\; (Vt_{fp} - Vt_{fr1})$$

Average boat speed (ABS)

$$\mathbf{ABS} = (Vd_{c2} - Vd_{c1}) \;/\; (Vt_{c2} - Vt_{c1})$$

Average Drive speed as a percentage of the average boat speed (DSPBS).

DSPBS = ADS / ABS

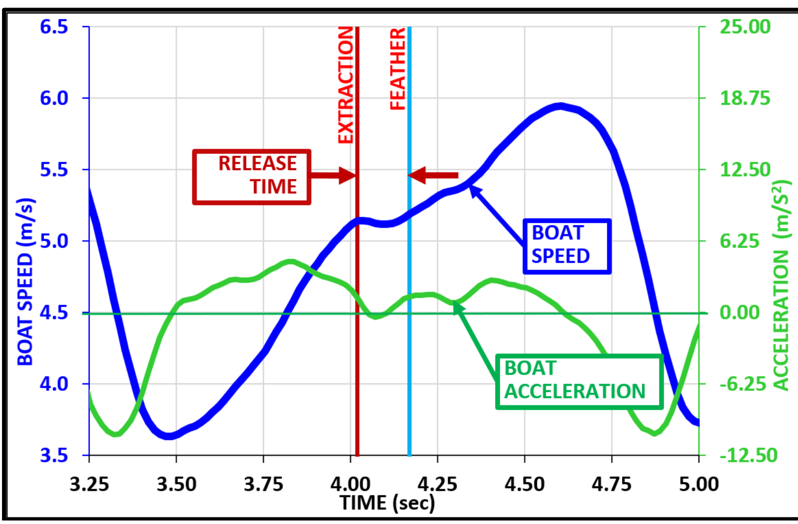
where:
$\boldsymbol{Vd_{c1}}$ = video boat distance catch 1
$\boldsymbol{Vd_{c2}}$ = video boat distance catch 2
$\boldsymbol{Vd_{fp}}$ = video boat distance feather (finish)
$\boldsymbol{Vd_{fr1}}$ = video boat distance full reach 1
$\boldsymbol{Vt_{c1}}$ = video boat distance catch 1
$\boldsymbol{Vt_{c2}}$ = video boat distance catch 2
$\boldsymbol{Vt_{fp}}$ = video boat distance feather (finish)
$\boldsymbol{Vt_{fr1}}$ = video boat distance full reach 1

The drive speed as a percentage of the average boat speed represents a factor value related to an effective drive phase.

2.9.4 Release Time

Release time is the time between blade extraction and the blade being fully feathered, Figure 2.9.4a, Release Time. The oar blade begins the release when it starts to travel in the same direction as the boat, typically when it is half out of the water. As the release begins, the hands are nearing the body, drawing down to extract the blade. The torso reaches full layback before extraction begins, and the legs stop pushing as the athlete draws the oar handle to the body. The goal is to cleanly extract the blade from the water while minimizing the time required to rotate it to the feather position.

Figure 2.9.4a *<u>Release Time</u>*



RELEASE TIME = $\boldsymbol{Vt_{fp} - Vt_{ex}}$

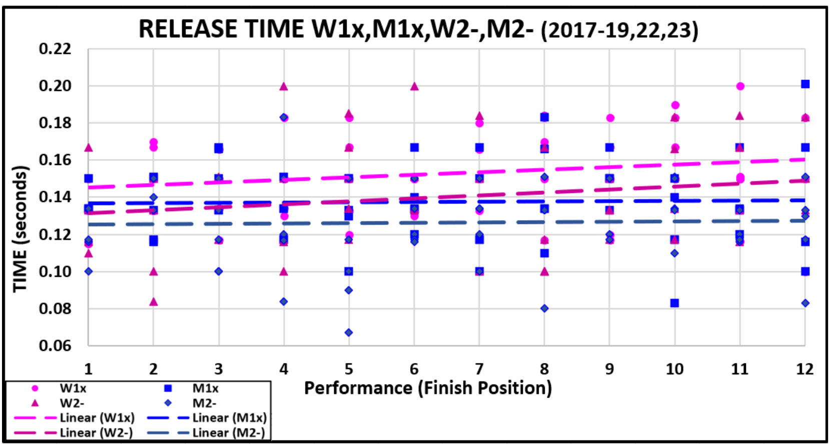
where: $\boldsymbol{Vt_{ex}}$ - video time blade extraction
$\boldsymbol{Vt_{fp}}$ - video time feather (finish)

Many coaches will consider that the release begins when the blade starts its vertical movement out of the water. The author provides the above definition as the oar continues to apply force on the oarlock until the blade begins to move in the same direction as the boat, though admittedly, it has started the extraction from the water.

The release time measures the blade extraction from the water and follows the late drive stage of the stroke, where the athlete works to maintain the blade in the water as long as possible to extend the effective stroke length. The longer the athletes can keep the blade buried, the further the boat will move. It appears that the release time itself is not a performance factor but relates to the effective stroke length, which is a rigging performance factor.

Figure 2.9.4b Release Time Singles Pairs shows data from the crews at the World Championships plotting their release time with their finish positions (1st to 12th).

Figure 2.9.4b *Release Time Singles Pairs*



The quick and clean release of the blade from the water during the extraction is critical to maintaining boat speed.

The release speed change is a technique factor measurement that provides objective data on the release efficiency. The release boat speed change is the difference in boat speed between extraction and the feather.

RELEASE BOAT SPEED CHANGE = $Vs_{fp} - Vs_{ex}$

where: Vs_{ex} - video interval boat speed extraction
Vs_{fp} - video interval boat speed feather (finish)

The change in boat speed between the extraction and the feather (finish position) reflects the effectiveness of the release. Release inefficiencies such as dragging the blade from the water (sloppy release) or pushing on the footstops after the extraction point will slow the boat's speed.

Figure 2.9.4c *Release Time Data*

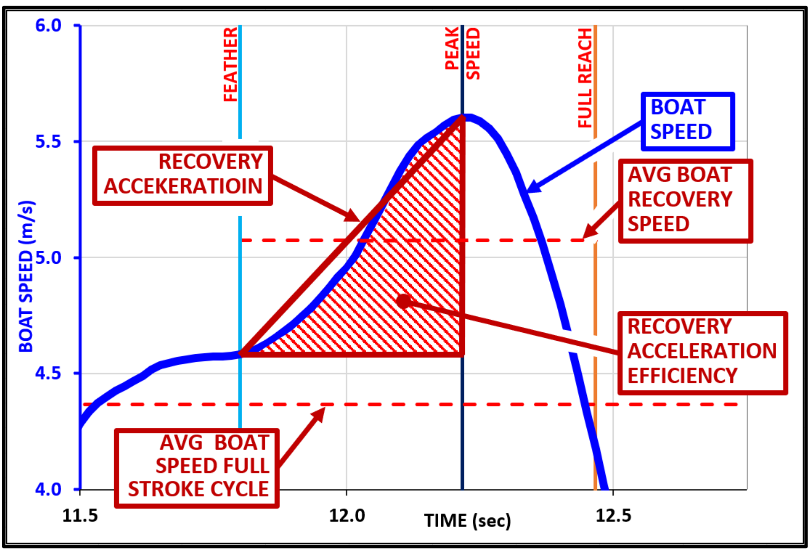
Boat Class	**Release Time**	Standard Deviation	Min.	Max	**% of Cycle**	Data Ref. (# of crews)
W1x	**0.15**	0.03	0.10	0.25	**8.6%**	(59) WC '17,'18,'19,'22,'23
W2x	**0.15**	0.01	0.13	0.18	**9.2%**	(16) WC '19, '22, '23
W4x	**0.13**	0.07	0.15	0.18	**7.9%**	(18) WC '17,'23
W2-	**0.14**	0.03	0.08	0.20	**8.5%**	(59) WC '17,'18,'19,'22,'23
W4-	**0.13**	0.02	0.10	0.18	**8.2%**	(18) WC '19,'23
W8+	**0.13**	0.02	0.10	0.17	**8.3%**	(40) WC '17,'18,'19,'22,'23
M1x	**0.14**	0.02	0.08	0.20	**8.3%**	(59) WC '17,'18,'19,'22,'23
M2x	**0.14**	0.02	0.10	0.18	**8.9%**	(17) WC' 19,' 22, '23
M4x	**0.12**	0.02	0.08	0.15	**7.3%**	(14) WC '17,'23
M2-	**0.13**	0.02	0.07	0.18	**8.0%**	(60) WC '17,'18,'19,'22,'23
M4-	**0.12**	0.02	0.08	0.15	**7.7%**	(18) WC '17,'19,'23
M8+	**0.12**	0.02	0.08	0.15	**7.6%**	(51) WC '17,'18,'19,'22,'23

The release time and the release boat speed change are two technique factors that provide objective values for the efficiency of the release. The release phase of the stroke should not be underestimated as to its value toward performance.

2.9.5 Recovery Acceleration

During the recovery at a racing rate, the boat will accelerate and decelerate as the athletes move from the finish position to the full reach position at the catch. In the first half of the recovery, the boat accelerates as the athletes pull their footstops toward their seats. The recovery acceleration technique factor is the measured linear boat acceleration between the feather (finish position) and the boat's peak speed, Figure 2.9.5a.

Figure 2.9.5a *Recovery Acceleration*



Recovery acceleration is calculated as the change in speed divided by the change in time between the feather and peak boat speed.

$$\textbf{RECOVERY ACCELERATION} = \frac{(Vs_{pk} - Vs_{fp})}{(Vt_{pk} - Vt_{fp})}$$

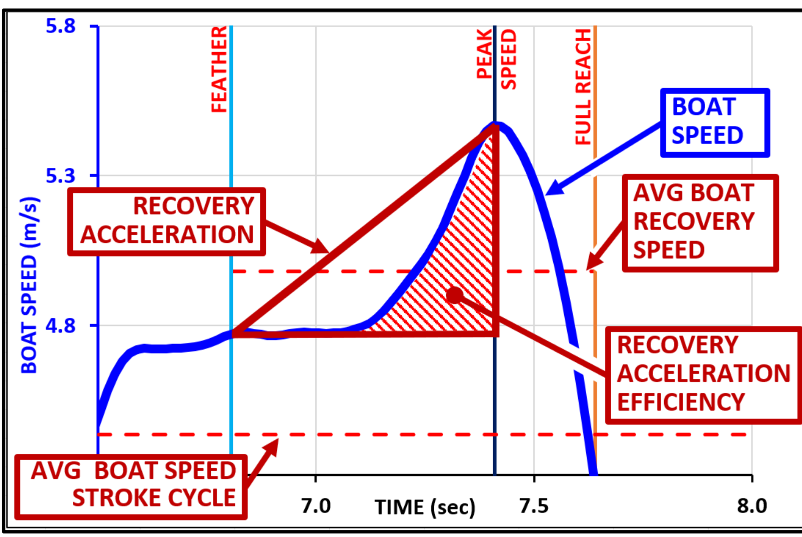
where: Vs_{fp} - video frame interval speed feather
Vs_{pk} - video frame interval speed peak
Vt_{fp} - video frame time feather
Vt_{pk} - video frame time peak speed

Boat acceleration on the recovery is possible because the athletes' centre of mass (COM) slows as they transfer their momentum to accelerate the boat. The boat's acceleration is much greater than the athlete's deceleration because the athlete or crew have a much greater mass than the boat and, therefore, much more momentum.

Boat acceleration is only possible when the athlete's mass accelerates toward the stern. The force applied by the athletes pulling on the footstops to accelerate the boat is calculated as F=ma and must be greater than the resistance on the boat. Higher acceleration rates increase the force applied, resulting in greater boat speeds on the recovery. At lower practice stroke rates, the athletes' acceleration on the slide is low, resulting in lower force and minimum or lost boat acceleration.

Another related technique factor is recovery acceleration efficiency (RAE). Recovery acceleration efficiency is shown in Figure 3.9.5b, represented by the hatched area under the boat speed curve between feather and peak speed.

Figure 2.9.5b *Recovery Acceleration Efficiency*



Recovery acceleration efficiency reflects the actual boat movement, and the area under the boat speed curve is a percentage of the straight-line acceleration between feather and peak speeds. The recovery acceleration efficiency represents the crew's ability to accelerate the boat effectively.

Boat acceleration is most effective at a consistent rate without quick or uneven changes. Sudden increases in the rate of acceleration will lead to short surges in boat speed, increasing wave propagation and resistance on the hull. Constant acceleration continued as long as possible during the recovery will be most effective for maximum recovery speed.

Calculation for Recovery Acceleration Efficiency (RAE):

$$\mathbf{RAE} = \frac{[\,(Vd_{pk} - Vd_{fp}) - Vs_{fp} \cdot (Vt_{pk} - Vt_{fp})\,]}{[\,(Vs_{pk} - Vs_{fp}) \cdot (Vt_{pk} - Vt_{fp}) / 2\,]}$$

where: Vd_{fp} - video boat distance feather
Vd_{pk} - video boat distance speed peak
Vs_{fp} - video frame interval speed feather
Vs_{pk} - video frame interval speed peak
Vt_{fp} - video frame time feather
Vt_{pk} - video frame interval speed peak

Figure 2.9.5b Recovery Acceleration Efficiency shows a speed curve with no increase in boat speed in the first third of the recovery. This rowing technique may be less effective as the RAE technique factor value is 46.1 percent, while the average for the boat class is 82.4 percent. The ineffective rowing technique supposition is supported by the boat's average recovery speed compared to the overall boat's average speed.

The *Recovery Speed as a Percentage of Boat Speed* (RSPBS) provides another technique factor evaluation. This factor requires a calculation of the boat's average recovery speed (ARS) between the feather and the full reach positions. It also involves calculating the average boat speed (ABS) through the complete stroke cycle.

The average boat speed on the recovery compared to the average boat speed for the full stroke cycle reflects the ability of the crew to transfer their body momentum to the boat on the recovery. The following calculations will provide the value for the RSPBS.

Average recovery speed (ARS)

$$\mathbf{ARS = (}\boldsymbol{Vd_{fr2} - Vd_{fp}}\mathbf{)\ /\ (}\boldsymbol{Vt_{fr2} - Vt_{fp}}\mathbf{)}$$

Average boat speed (ABS)

$$\mathbf{ABS = (}\boldsymbol{Vd_{c2} - Vd_{c1}}\mathbf{)\ /\ (}\boldsymbol{Vt_{c2} - Vt_{c1}}\mathbf{)}$$

Recovery speed as a percent of boat speed (RSPBS)

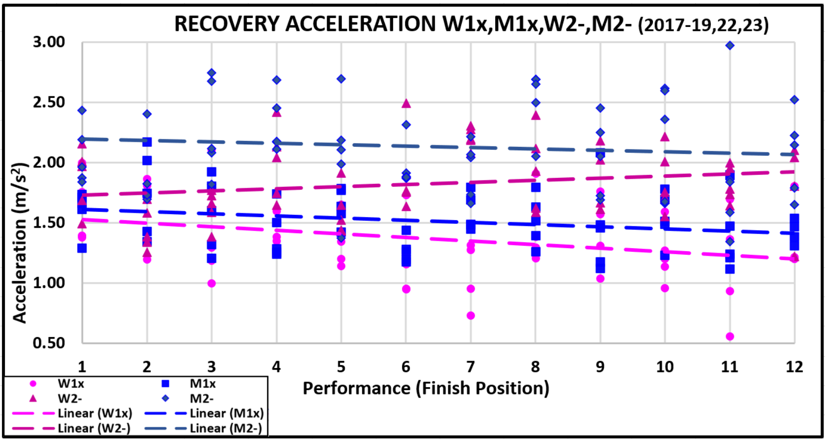
$$\mathbf{RSPBS = ARS\ /\ ABS}$$

where: $\boldsymbol{Vd_{c1}}$ = video boat distance catch 1
$\boldsymbol{Vd_{c2}}$ = video boat distance catch 2
$\boldsymbol{Vd_{fp}}$ = video boat distance feather (finish)
$\boldsymbol{Vd_{fr2}}$ = video boat distance full reach 2
$\boldsymbol{Vt_{c1}}$ = video boat distance catch 1
$\boldsymbol{Vt_{c2}}$ = video boat distance catch 2
$\boldsymbol{Vt_{fp}}$ = video boat distance feather (finish)
$\boldsymbol{Vt_{fr2}}$ = video boat distance full reach 2

The recovery speed, as a percentage of the average boat speed shown in Figure 2.9.5b, is 112.3%, indicating the boat speed is 12.3% above average. The average from the World Championship data for the boat class is 113.5%, which supports the low RAE factor value and suggests an ineffective recovery.

Figure 2.9.5c Recovery Acceleration Singles Pairs shows data from crews at the World Championships plotting their recovery accelerations with their finish positions (1st to 12th).

Figure 2.9.5c *Recovery Acceleration Singles Pairs*



The resistance in the system reflects drag from the hull, water, wind, and wave propagation. Unsteady flow may increase resistance.

Figure 2.9.5d *Recovery Acceleration Data*

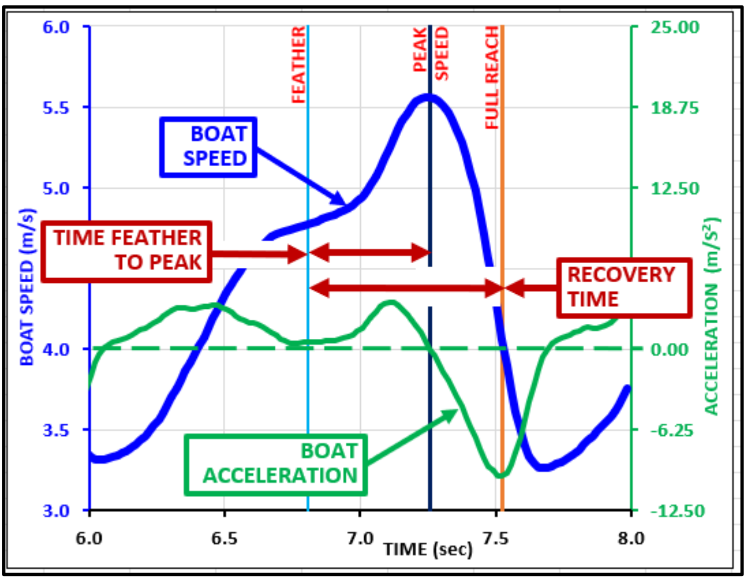
Boat Class	Rec. Accel.	Standard Deviation	Rec. Eff.	Standard Deviation	Av. Spd % Cyc.	Standard Deviation	Data Ref. (# of crews)
W1x	1.40	0.35	82.4%	13.2%	113.5%	1.2%	(59) WC '17,'18,'19,'22,'23
W2x	1.73	0.32	90.6%	9.2%	112.9%	1.1%	(16) WC '19, '22, '23
W4x	1.74	0.36	95.8%	7.4%	112.6%	1.3%	(18) WC '17,'23
W2-	1.83	0.30	94.2%	9.5%	114.1%	1.1%	(59) WC '17,'18,'19,'22,'23
W4-	1.96	0.27	97.1%	7.2%	113.7%	1.0%	(18) WC '19,'23
W8+	1.98	0.25	101.6%	7.0%	111.9%	0.8%	(40) WC '17,'18,'19,'22,'23
M1x	1.52	0.25	86.3%	11.2%	113.7%	1.1%	(59) WC '17,'18,'19,'22,'23
M2x	1.56	0.31	92.9%	11.9%	112.6%	1.0%	(17) WC' 19,' 22, '23
M4x	1.78	0.29	95.2%	6.7%	112.5%	0.7%	(14) WC '17,'23
M2-	2.13	0.41	97.8%	9.1%	114.5%	1.4%	(60) WC '17,'18,'19,'22,'23
M4-	2.33	0.34	99.5%	7.8%	114.3%	0.9%	(18) WC '17,'19,'23
M8+	2.14	0.32	101.8%	9.5%	111.9%	0.6%	(51) WC '17,'18,'19,'22,'23

The movement of the athletes during recovery is key to effective rowing technique. Higher stroke rates with lower recovery times will increase the boat's recovery speed. However, the recovery must address acceleration and acceleration efficiency to maximize efficiency.

2.9.6 Recovery Peak Speed

Boat acceleration on the recovery is caused by the athlete pulling (accelerating) the footstops towards their body's centre of mass as they move from the finish position toward the catch. Recovery peak boat speed (RPS) is the percentage of the recovery time (feather to full reach) the boat takes to achieve peak speed. Figure 2.9.6a Recovery Peak Speed identifies the recovery time and the time to feather to peak speed.

Figure 2.9.6a *Recovery Peak Speed*



The peak boat speed as a percentage of the recovery time is calculated by dividing the recovery time by the time feather to peak, as shown in the following calculation.

$$\textbf{RPS} = (Vt_{ps} - Vt_{fp}) / (Vt_{fr2} - Vt_{fp})$$

where: Vt_{fp} - video time feather
Vt_{fr2} - video time full reach 2
Vt_{ps} - video time peak boat speed

The recovery to peak speed percentage measures the crew's ability to extend boat acceleration during recovery. Figure 2.9.6b Percent to Peak Singles Pairs includes trendlines for each boat class that suggest higher percentages may be a performance factor.

Figure 2.9.6b *Percent to Peak Singles Pairs*

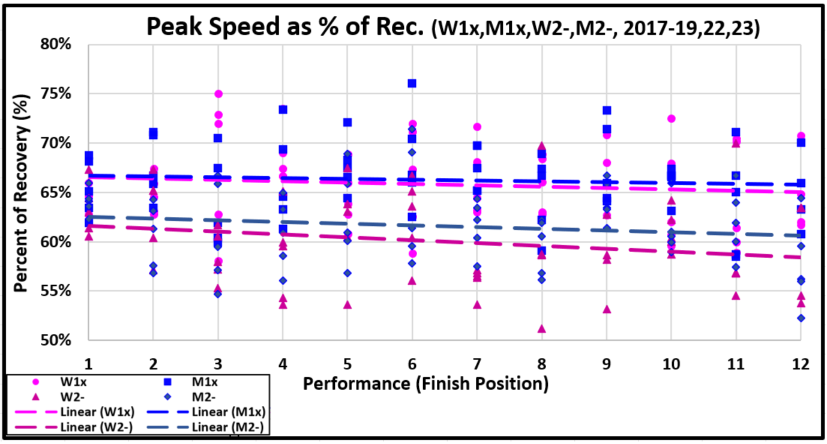


Figure 2.9.6c Percent to Peak Data shows the values for various boat classes at the World Championships. The data also includes the standard deviation, minimum, maximum, and the number of crews in the sample.

Figure 2.9.6c *Percentage to Peak Data*

Boat Class	**Peak Spd. % Rec.**	Standard Deviation	Min.	Max	Data Ref. (# of crews)
W1x	**65.9%**	4.1%	58.1%	75.0%	(59) WC '17,'18,'19,'22,'23
W2x	**61.8%**	3.3%	55.8%	66.0%	(16) WC '19, '22, '23
W4x	**61.3%**	2.7%	56.3%	65.9%	(18) WC '17,'23
W2-	**60.1%**	4.5%	51.2%	70.0%	(59) WC '17,'18,'19,'22,'23
W4-	**60.1%**	3.6%	51.2%	65.2%	(18) WC '19,'23
W8+	**58.4%**	3.7%	49.0%	64.3%	(40) WC '17,'18,'19,'22,'23
M1x	**66.2%**	3.8%	58.5%	76.0%	(59) WC '17,'18,'19,'22,'23
M2x	**64.4%**	4.2%	56.6%	71.4%	(17) WC' 19,' 22, '23
M4x	**63.0%**	3.7%	56.5%	69.5%	(14) WC '17,'23
M2-	**61.6%**	3.9%	52.3%	71.4%	(60) WC '17,'18,'19,'22,'23
M4-	**60.7%**	4.2%	53.4%	68.9%	(18) WC '17,'19,'23
M8+	**60.4%**	4.4%	47.6%	67.5%	(51) WC '17,'18,'19,'22,'23

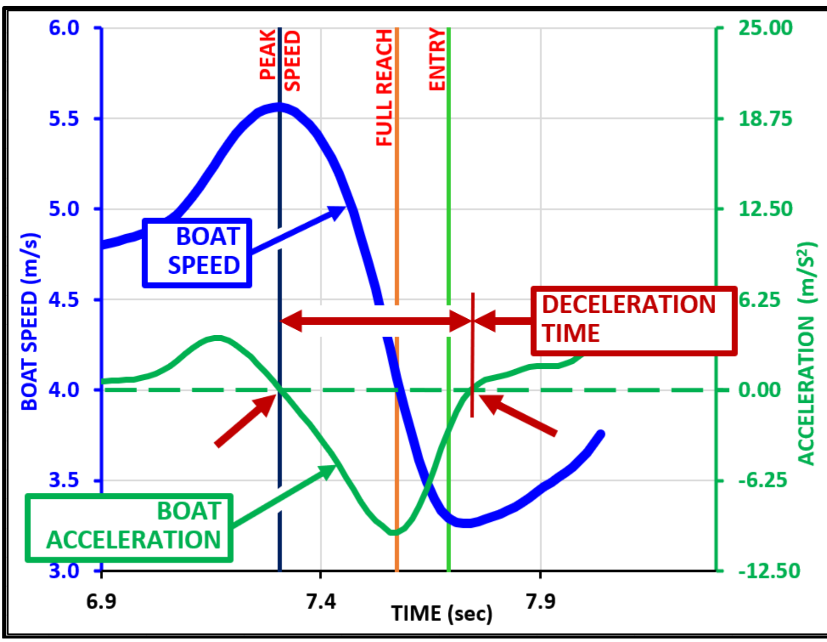
The ability of the crew to extend boat acceleration during recovery is critical to performance. The rowing technique utilized is called dynamic recovery, meaning the arms, torso and legs work together to move the bodies from the finish position to full reach. The momentum from the athlete's centre of mass must be transferred to the boat through the legs by pulling on the footstops. Acceleration on the recovery is critical, as constant speed on the slide results in the boat slowing due to resistance on the hull. The acceleration rate must be high enough to provide a force greater than the force of the resistance on the hull, or the boat will slow.

The key to extending peak speed is that the athletes in the crew must move together on the slide at the same constant acceleration rate and as far as possible toward the next full reach. Extended crew acceleration toward the next catch requires the crew to have a very effective catch that minimizes entry time.

2.9.7 Deceleration Time

The deceleration time technique factor is the length of time the boat experiences negative acceleration following the boat's peak speed on the recovery. When racing, the boat achieves peak speed at half to two-thirds through the recovery and then decelerates rapidly as the crew slows its movement toward full reach. Figure 2.9.7a Deceleration Time shows the green boat acceleration curve rapidly dropping below the horizontal green dashed line representing zero acceleration on the graph. When the green acceleration curve is below the horizontal green dashed line, the boat decelerates, and the red arrows highlight the deceleration time.

Figure 2.9.7a *Deceleration Time*



Deceleration time extends through the late recovery and the blade entry phases and ends when the boat achieves positive acceleration near the blade entry. The following formula is used to calculate deceleration time.

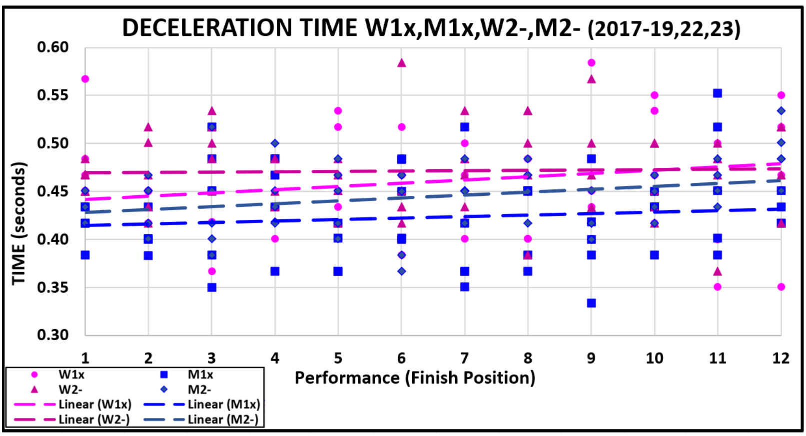
DECELERATION TIME = $Vt_{ps} - Vt_{pac2}$

where: Vt_{ps} - video time peak boat speed
Vt_{pac2} - video time positive acceleration catch2

The deceleration time factor value represents the crew's ability to transition quickly from accelerating the boat on the recovery to accelerating the boat on the drive.

Figure 2.9.7b Deceleration Time Singles Pairs shows data from the World Championships, including trendlines for each category.

Figure 2.9.7b. *Deceleration Time Singles Pairs*



Minimizing the time the boat decelerates is key to maximizing average boat speed, making deceleration time a performance factor. Crews can minimize deceleration time by extending the boat's peak speed later into the recovery, as discussed in Section 2.9.6 Recovery Peak Speed. Additionally, reducing entry time (Section 2.9.1) will allow the boat to accelerate sooner in the drive, reducing deceleration time. The crew must develop the skill to reverse direction quickly and minimize deceleration time.

Extending peak speed and reducing entry time must be practiced and improved together to minimize deceleration time effectively. Practices at low rates can double the time the crew is on the recovery, and athletes can extend recovery peak speed as they accelerate toward the full reach position. At the same time, entry drills must improve the blade approach, entry, and connection. Not developing the two skills together may lead to other technical errors.

Figure 2.9.7c Deceleration Time Data shows the values for various boat classes at the World Championships. The data on the chart includes the average deceleration time values for crews in each boat class. The chart also includes the standard deviation, minimum and maximum values for each category, the percentage of stroke cycle time, and the number of crews in the sample.

Figure 2.9.7c *Deceleration Time Data*

Boat Class	**Decel. Time**	Standard Deviation	Min.	Max	% of Cycle	Data Ref. (# of crews)
W1x	**0.46**	0.06	0.35	0.62	25.8%	(59) WC '17,'18,'19,'22,'23
W2x	**0.47**	0.04	0.40	0.55	28.4%	(16) WC '19, '22, '23
W4x	**0.48**	0.03	0.42	0.53	29.1%	(18) WC '17,'23
W2-	**0.47**	0.04	0.37	0.58	28.4%	(59) WC '17,'18,'19,'22,'23
W4-	**0.48**	0.04	0.40	0.57	29.4%	(18) WC '19,'23
W8+	**0.51**	0.04	0.42	0.60	31.9%	(40) WC '17,'18,'19,'22,'23
M1x	**0.42**	0.05	0.33	0.55	25.3%	(59) WC '17,'18,'19,'22,'23
M2x	**0.42**	0.04	0.37	0.52	26.7%	(17) WC' 19,' 22, '23
M4x	**0.49**	0.06	0.42	0.62	30.4%	(14) WC '17,'23
M2-	**0.44**	0.03	0.37	0.53	28.3%	(60) WC '17,'18,'19,'22,'23
M4-	**0.46**	0.04	0.38	0.53	29.6%	(18) WC '17,'19,'23
M8+	**0.49**	0.04	0.38	0.57	31.7%	(51) WC '17,'18,'19,'22,'23

The data in Figure 2.9.7c show that the deceleration time is less than half of a second at the highest levels of rowing. Minimizing this time is a factor of performance and requires advanced technical skills. In crew boats, all athletes must accelerate towards the catch together to transfer their body momentum to increase boat speed. The further on the recovery the crew accelerates, and the quicker the entry time, the lower the deceleration time.

The Purcerverance Boat Speed Analysis calculates eighty-seven factor values to evaluate performance. This section has presented only a few and related the values to rowing technique. Section 2, Speed Curve Development, outlines video capture and boat speed and technique data extraction from the video.

Analyzing the video to find technique factor values has identified opportunities for the crew to improve speed. Comparing the crew's technique factor values with sample values may motivate the crew to improve. The sample factor values in this section are averages and should be the minimum targets for a crew. These values reflect technique factor measurements and what crews are capable of.

Figure 2.9.7d *Curve Math*