

Results From Hydraulic Evaluation Of Cone Screens At Tehama Colusa Canal Authority's Interim Pumping Plant, May 10 – September 2, 2010, Red Bluff, California

Team of evaluation participants:

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Background

Reclamation built the interim pumping plant as a stopgap measure in early 2009 to divert water from the Sacramento River to the Tehama Colusa (TC) Canal during annual “gates out” periods for the three years of construction of a long-term pumping plant. Designed in response to a December 2008 mandate for delaying “gates in” operation of the Red Bluff Diversion Dam (RBDD) until June annually, beginning in 2009, the plant uses the most readily available “off-the-shelf” technology.

The interim pumping plant has ten vertical pumps each with a design capacity of 50 cfs (Figure 1). Pumps 1 through 5 and 10 are 300 Horsepower (HP), while Pump 6 is 350 HP and Pumps 7 through 9 are 400 HP. Pumps are paired to feed five, 36 inch conveyance pipes that lead to the settling basin at the head of the TC Canal. Each pump is screened with a 14 ft diameter conical fish screen manufactured by Intake Screens, Inc (ISI). Each screen has a total surface area of approximately 180 square feet and has a rotating brush cleaning system for debris removal that operates on a programmable timer. Conical screens were developed to operate in tidal and back water areas where water depths are shallow and there is no dominant current in the water body. They were chosen for this project based on the shallow water conditions at the proposed site even though it was doubtful that approach and sweeping velocity criteria could be met with this screen design¹. A condition of accepting the proposed design was that velocities would be measured across the surface of each screen and the results provided to DFG and NMFS to assure they meet state and federal fish screening criteria². An initial hydraulic evaluation of the cone screens was made on June 1-10, 2009 by an interagency team (U.S. Fish and Wildlife Service 2010).

Goal of Hydraulic Evaluation

Goals of fish screen hydraulic evaluations are typically 1) to measure near screen water velocities under a near worst case scenario of diversion rate and river flows expected to be encountered throughout the life of the facility; and 2) to adjust flow control baffles to distribute flow uniformly over the entire screen surface. Given the atypical use of the cone screen

¹ NMFS fish screen criteria document, *Fish Screening Criteria for Anadromous Salmonids* (1997) states, “screen design must provide for uniform flow distribution over the surface of the screen, thereby minimizing approach velocity.” The CDFG document, *Fish Screening Criteria* (June, 2000) states, “[t]he design of the screen shall distribute the approach velocity uniformly across the face of the screen.”

² Refer to conditions 6.4 and 6.7 of Incidental Take Permit No. 2081-2009-006-01 issued by the California Department of Fish and Game.

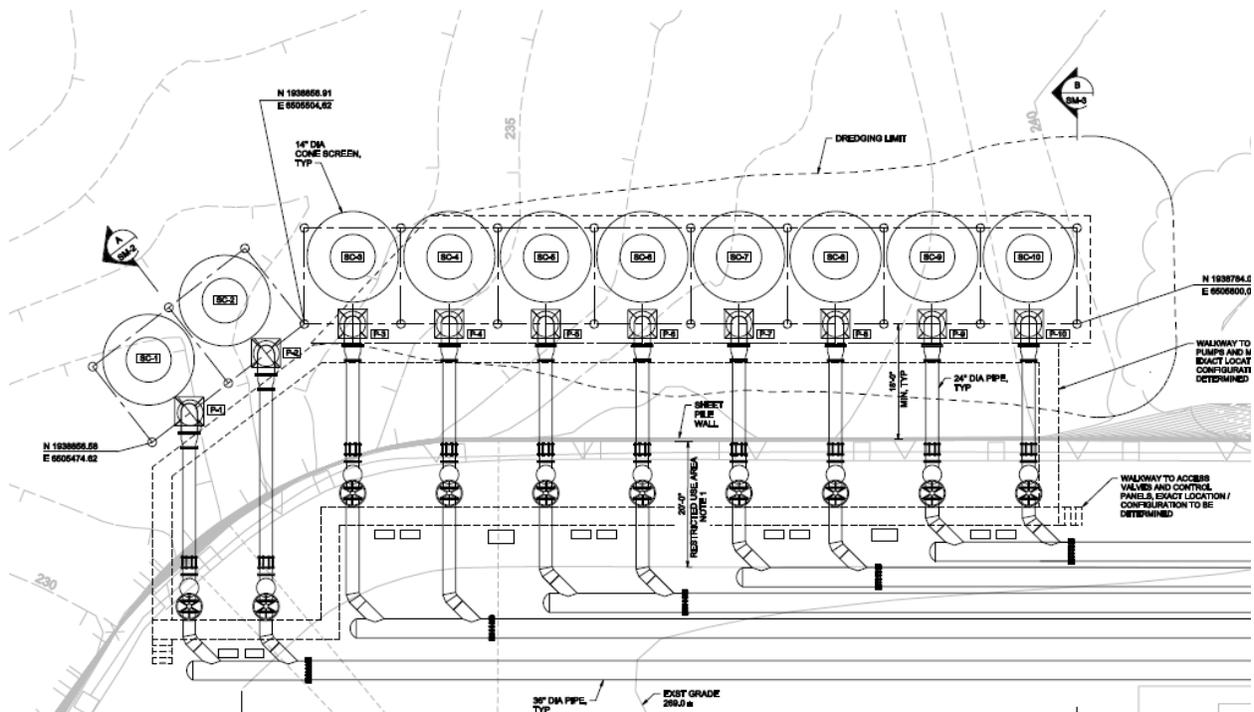


Figure 1. Layout of pumps and screens at the interim pumping plant. Screens and pumps were numbered 1 through 10, left to right.

technology at the interim pumping plant, there was a third goal to this evaluation: to determine whether or not the cone screens could be operated in conformance with the State and federal fish screening criteria. The goal of the 2010 testing was to evaluate the hydraulic performance of the cone screens under a range of river flows and pump operating conditions. An additional goal was to determine if potential impingement would occur at the screens even if the pumps were not operating. The null hypotheses for the above goals were: 1) that the cone screens, under a range of river flows and pump operating conditions, would meet State and federal fish screening criteria; and 2) that potential impingement would not occur at the screens even if the pumps were not operating.

Methods

A SonTek 16 MHz Acoustic Doppler Velocimeter (ADV) was used to measure near-screen velocities in three dimensions: X, Y, and Z. The ADV was positioned such that approach velocity was measured directly by the X component of the probe. Sweeping velocities were calculated as the resultant of Y and Z measured values. Raw data for each location were stored in separate files and processed with WinADV, a program developed by the U.S. Bureau of Reclamation. Point-average velocities were processed with Microsoft Excel to produce charts and graphs. Total discharge for each screen was calculated based on screen area and approach velocities as a quality control procedure. The formula to calculate the total discharge was as follows:

$$\text{Total Discharge} = \sum \text{screen area}_{\text{depth position } i} \times \text{average approach velocity}_{\text{depth position } i}$$

Data were collected on three occasions between May 10 and September 2 as shown in Table 1. Pumps were operating on May 10-13 and August 31- September 2 but were not operating on June 7-10. Pump 10 was out of commission on August 31- September 2. A shallow draft, aluminum boat owned and operated by USFWS was used to provide safe access to the screens. The boat was tied up to structural piles typically within four feet of the top of each screen unit. This distance was thought to provide sufficient buffer against interference with screen velocities.

Screen area was divided into forty eight zones in an array of six depths and eight positions (bearings) around each screen unit for pumps 2 through 10 (Figures 2 and 3) and into ninety six zones in an array of six depths and sixteen bearings for pump 1. Velocity measurements were taken at or near the center of each zone. Positions for each measurement along each bearing and screen area for each zone are shown in Figure 4. ISI manufactured a jig to position the probe that attached to the screens' cleaning systems (Figure 4, Photo 1). By operating the cleaning system and adjusting the jig the ADV could measure near-screen velocities three inches from the screen face at nearly any point on the screen. The probe size prevented measuring velocities within the top two feet on each screen (Photo 2). Velocity measurements were recorded at a rate of 25Hz for a minimum of 60 seconds.

Results and Analysis

Plots of approach velocity and sweeping velocity data are shown in Appendices A and B, respectively. The plots show the distribution of velocities around the screen, with different lines for each position vertically on the screen. For the approach velocities, velocities that fall within the red polygon are negative approach velocities, where flow was coming out of the screen. Approach velocities on Screens 8 – 10 did not exceed 0.45 fps, but none of these screens consistently had approach velocities well distributed over all screen areas. Approach velocity distribution on screen numbers 1 – 5 were heavily influenced by the river current. Approach velocities in areas receiving direct impact of the current (i.e. the upstream surface of the screens) far exceeded the design target value. Velocity data indicate water will pass through the porous cones, entering the upstream side and exiting the downstream side. All screens showed water exiting the screen, indicated by negative approach velocities in the plots in Appendix A, for at least one location during at least one sampling period, although this effect was most pronounced for Screen 1.

Although the steel plate on the upstream side of Screen 1 successfully reduced flow through what would likely otherwise had been the hottest spot³ on all screens, there were still high approach velocities on either side of the steel plate. Approach velocity measurements at bearing 270 degrees were taken directly over the solid plate and ranged from 0.17 to 0.56 fps when pump 1 was operating, despite having a solid barrier three inches away. Approach velocities to either side of the barrier plate at bearings 247.5 and 292.5 ranged from 0.41 to 1.28 and 0.82 to 1.41 fps, respectively, when pump 1 was operating. It is unknown what effect the plate had on approach velocities elsewhere on the screen. On a mass balance basis, the elimination of flow intake from the portion of the screen covered with the steel plate will increase approach velocities elsewhere on the screen. However, the plate accelerates flow parallel to the screen face immediately to the edge of the plate, possibly drawing water out of the screen due to the

³ The hottest spot refers to the location on the screen with the highest approach velocity.

Table 1. Pumping plant and river data.

Screen #/ Pump Pair	Date Tested	Recorded Paired Pumping Rate (cfs)	Measured Paired Pumping Rate (cfs)	River Flow at Bend Bridge (cfs)
7 & 8	5/10/10	47-76.6 ⁴	38.1, 24.3 ⁵	9,930
9 & 10	5/11/10	81.3 – 81.9	97.7	10,400
5 & 6	5/11/10	90.6 – 90.7	94.3	10,400
1 & 2	5/12/10	90.4 – 91.3	97.5	9,770
3 & 4	5/12-13/10	91.6 – 91.8	94.6	9,510 - 9,770
1	5/13/10	0 ⁶	5.6 ⁷	9,510
4 & 5	6/7/10	0	9.4, 1.9	17,500
6 - 9	6/8/10	0	-2.4, 2.2, 0.3, 3.7	16,800
2 – 3 & 10	6/9/10	0	4.2, 17.6, 1.4	14,600
7 & 8	8/31/10	74.5 – 75.4	61.8	8,950
5 & 6	8/31/10	89 - 90	76.7	8,950
3 & 4	9/1/10	90.8 – 91.4	92.8	9,100
1 & 2	9/1/10	90.3 – 90.4	92.0	9,100
9	9/2/10	50.9	42.3	8,960

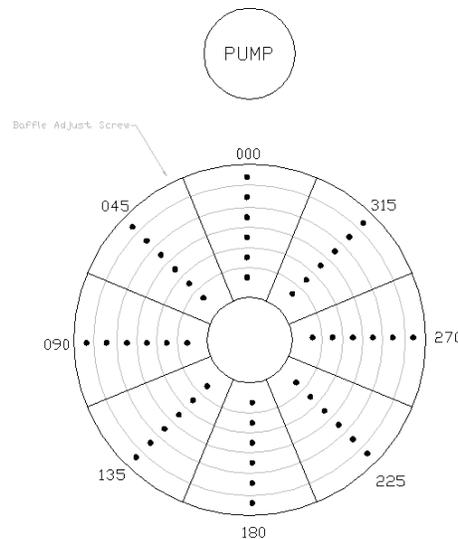


Figure 2. Plan view of locations for velocity measurements on each cone screen: six positions along each of eight bearing angles for a total of 48 measurement locations. The point naming convention used included the bearing angle (with “0” being closest to the pump column), and distance from the toe of the screen (0.5, 1, 2, 3, 4, 5) as shown in Figure 4.

⁴ The recorded flow for Pump Pair 7 & 8 was 47 cfs during testing of Screen 8 and was 76.6 cfs during testing of Screen 7.

⁵ The first flow was the individual pumping rate for Pump 7, the second flow was the individual pumping rate for Pump 8 excluding two outliers at bearing 135 (-0.75 fps at height 4 and -1.19 fps at height 5).

⁶ The flow rates of zero are the nominal flow since the pumps were off. On 5/13/10 with pumps 1 and 2 off, the recorded flow for this pump pair was negative 7 cfs.

⁷ Calculated excluding velocities measured at 270 degrees (directly over the metal plate).

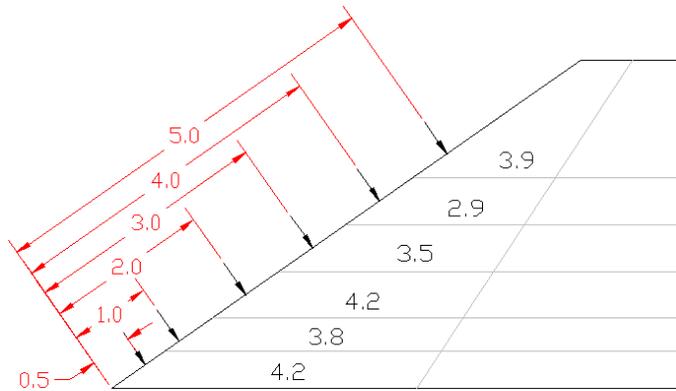


Figure 3. Partial section of a cone screen showing locations where water velocities were measured (arrows, distance values in feet) and the screen zone area associated with those measurements (square feet of screen area per zone). (Zones not shown to scale.)

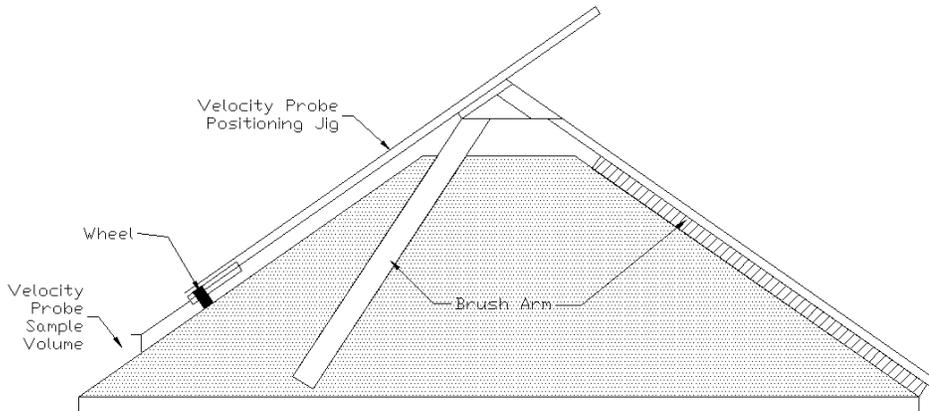


Figure 4. Diagram of equipment used for measuring velocities on cone screens. The jig arm could be raised or lowered to the appropriate elevation on the screen. The jig was attached to the rotating brush system for positioning the velocity probe around the circumference of the screen.



Photo 1. Mounting the velocity probe and positioning jig to the screen's cleaning system.



Photo 2. ADV probe in its highest position on the screen measured velocities two feet below the top of the screen panel.

Bernoulli effect (S. Thomas, personal communication). In any case, we recommend keeping the plate installed on Screen 1 to reduce approach velocities at what would have been the hottest spot on all screens.

Data collected when the pumps were not operating indicated that the high approach velocities were due to a combination of river current and pumping. Approach velocities exceeded 0.33 fps for at least one location for all screens except Screen 10 when the pumps were not operating. While the patterns of approach velocities were generally similar for the two sampling periods when the pumps were operating, there were some significant differences in some cases. For example, the approach velocities for Screen 8 were generally evenly distributed on May 10, but were not evenly distributed on August 31. This pattern indicates the importance of sampling under different conditions to fully evaluate the hydraulic conditions present around fish screens.

Sweeping velocities varied over a wide range depending on location. On Screen 1, sweeping velocities were 2 – 3 fps on the leading edge, 4 – 6 fps on either side, and approaching 0 fps on the downstream side. Sweeping velocity patterns were similar on Screens 2 and 3, but to a lesser magnitude. All screens had at least one point where the sweeping velocity was essentially zero.

Conclusions

Screens located in the main river current (Screens 1 – 3) had hot spots exceeding 1.0 fps, speeds that could present a serious hazard to juvenile salmonids and sturgeon, as well as other fish. Screens 4 - 6 also had hot spots in patterns similar to those on Screens 1 – 3, although to a lesser magnitude.

In 2009, with only 48 measurements, the overall average approach velocity on Screen 1 was less than zero, indicating more water was exiting the screen than entering it, which is erroneous since with the pump operating more water would be entering the screen than exiting it. The doubling of the number of measurement points on Screen 1 in 2010 substantially improved the diversion rate estimates, resulting in calculated diversion rates of 41.4 – 43.4 cfs. Accurate measurements of approach velocities when pumps are not in operation would likely require a similar level of effort, since with 48 measurements, differences between water entering and exiting the screen were as much as 17.6 cfs.

Comparisons of recorded and measured pumping rates (Table 1) indicate probable errors in both values. These data imply inaccuracies in the in line flow meters and errors in measurements of the approach velocities. If the actual diversion rate was less than what was measured, approach velocities will be greater and flow distribution may not be as uniform at the full diversion rate than they were when measured during this evaluation. There was no apparent pattern in recorded versus measured pumping rates, with recorded flows lower during the May sampling period but generally higher during the August to September sampling period. For a cone screen, theoretically diversion rates should be calculated by multiplying zone approach velocity by zone area where zone area is not actual screen areas but the area of a cone with a base diameter six inches greater than that of the screen (S. Thomas, personal communication). This would increase all calculated diversion rates and, theoretically, take into account water changing direction within the three inch area between the probe and screen. The accuracy of the measured

pumping rates is limited due to the finite number of measurement points practical for taking measurements and the turbulence in the system, so inaccuracies associated with the calculated pumping rates needs to be considered in evaluating this data.

Based on measurements, calculated from approach velocity measurements, when the pumps were off, the measured discharges typically overestimate the flow⁸ entering the screens, but the overestimate can range from 0.3 to 17.6 cfs. Errors in measured approach velocities are also suggested by two outliers on Screen 8 on May 10; while all of the other approach velocities were greater than zero in this case, the two outliers had measured approach velocities of -0.75 and -1.19 fps. Estimates of measured pumping rates likely could have been improved by measuring more velocities per screen. The measurements on pump 1 with the pump off suggest another possible source of error in the approach velocities, namely due to the velocities being measured three inches off the screen. The approach velocities of around 3 fps measured over the steel plate when pump 1 was off indicate that in some cases the current switches from approaching the screen to sweeping the screen at a distance closer than 3 inches from the screen.

Adjusting the flow control baffles on Screens 6 – 10 may be appropriate to increase the uniformity of flow distribution over the entire screen surface of those screens. Adjusting the existing baffles will not likely have much effect on water passing directly through screen units 1 – 5. A completely different baffle system which compartmentalizes screen sections, preventing flow from passing in one side and out the other, would greatly improve approach velocity distribution on screens located in an active current (i.e. Screens 1 – 5).

Sweeping velocity criteria were not always met, especially in the backwater area of Screens 6 – 10. When sweeping velocities are very low screen hot spots accumulate debris and present a greater hazard of impingement than a screen with greater sweeping velocities. In areas where sweeping velocities are very low manual debris removal is important to maintain satisfactory hydraulic conditions. Screen 7 appeared to have the biggest debris problem. Screen 10 had a one and a half foot by two foot sign that was adhering to the screen due to approach velocities on May 11, 2010; we removed the sign before starting velocity measurements. This observation suggests that manual inspection of the screens is needed on a regular basis to ensure that the screens are free of debris.

For most measurement locations, sweeping velocities exceeded approach velocities, in many cases by an order of magnitude or more. At those locations, fish coming in contact with the screen face will likely have sufficient velocity to be deflected off the screen and continue with the prevailing current. In areas where sweeping velocity is low, a screen with hot spots may lead to fish impingement (injury and/or mortality). Turbulence in the vicinity of Screens 1 – 4 may disorient juvenile fish allowing predator species to lie in wait in calmer waters for feeding opportunities.

⁸ Overestimate means any measured flow greater than zero since with the pumps off there should be no net flow entering the screens.

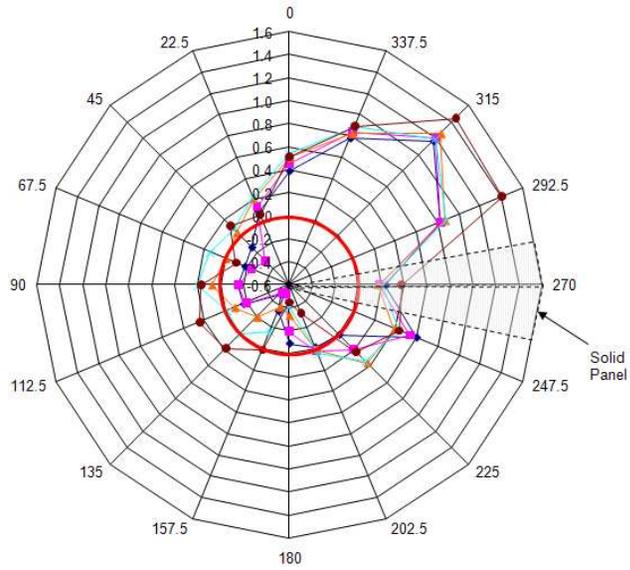
Reclamation's interim pumping plant at Red Bluff was designed and constructed in early 2009, using "off-the-shelf" technology. The technology was recognized as being problematic for use in flowing waters, but was the best option available in the time allowed. This monitoring study confirms that use of these conical screens is problematic in the face of a strong, dominant current. The 8 conical screens are best suited for the shallow tidal and backwater environments for which they were designed. In the presence of strong flows, problems consistently occur with hot spots and failures to meet approach criteria. It is recommended that the screens be removed following the 2011 irrigation season. When selecting where to reuse these screens, the screens should be used in tidal and back water areas where water depths are shallow and there is no dominant current in the water body. For 2011, the probability of impingement of fish onto the screen faces would be reduced by selectively using the downstream-most screens and minimizing pumping from the interim pumping plant, both in terms of pumping rates and length of time that the interim pumping plant is operated.

References

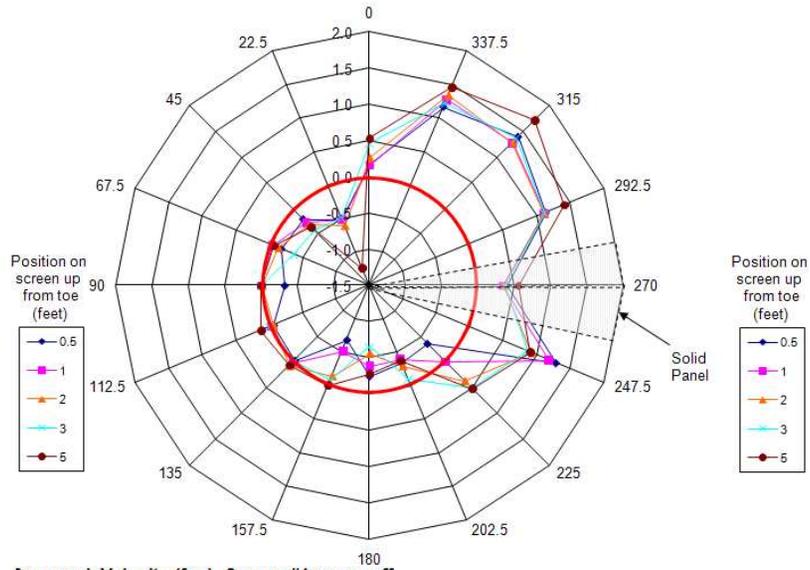
U.S. Fish and Wildlife Service. 2010. Identification of the instream flow requirements for anadromous fish in the streams within the central valley of California and fisheries investigations. U.S. Fish and Wildlife Service: Sacramento, CA.

Appendix A – Approach Velocities

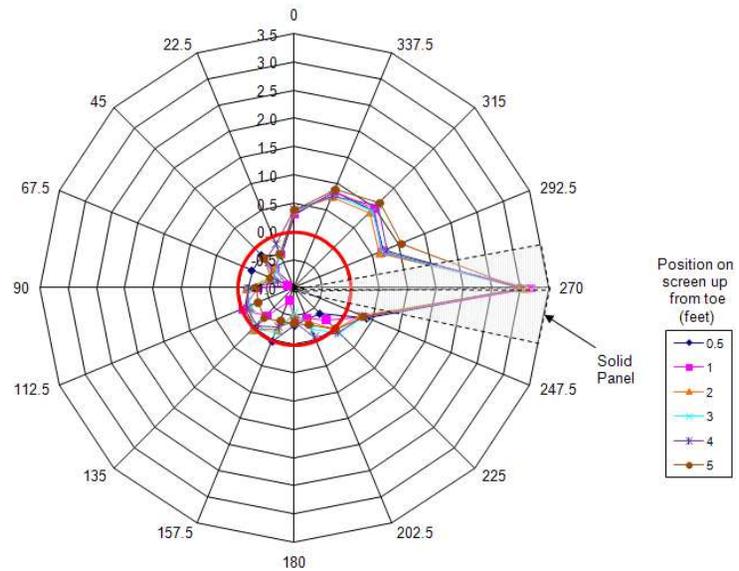
Approach Velocity (fps), Screen #1, 5/12/10



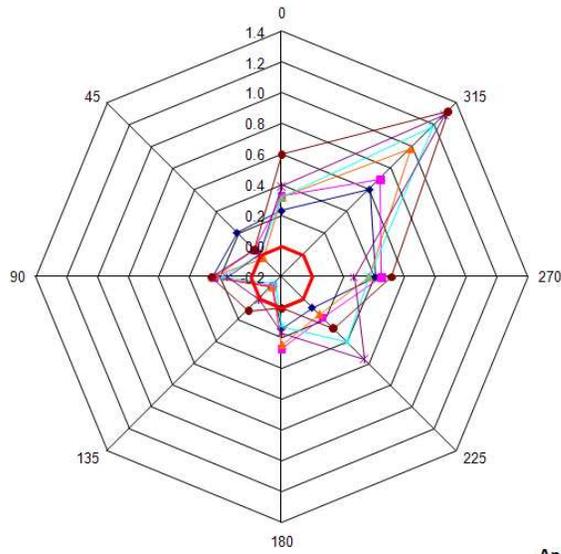
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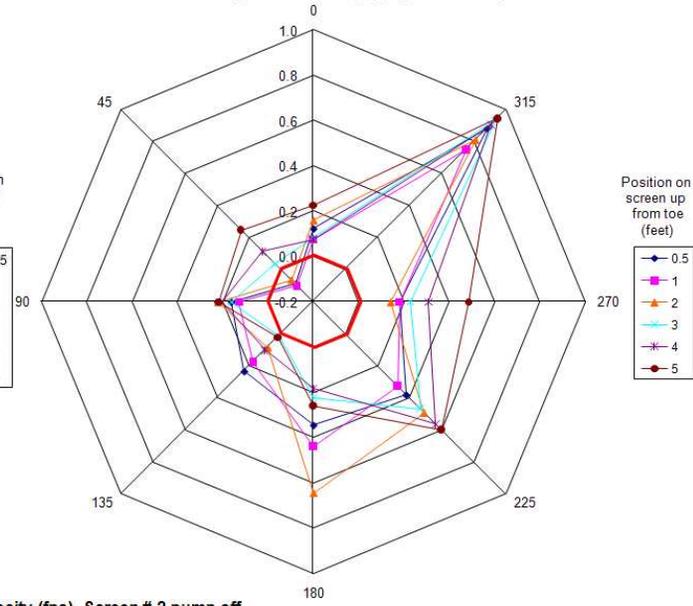
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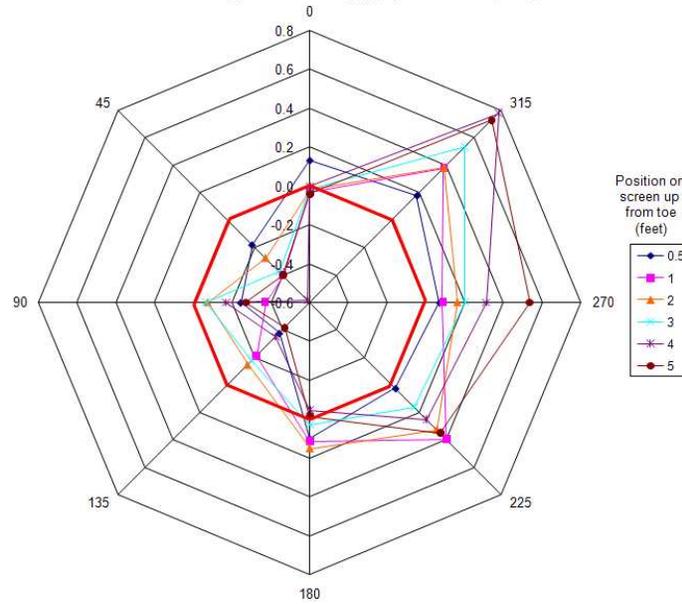
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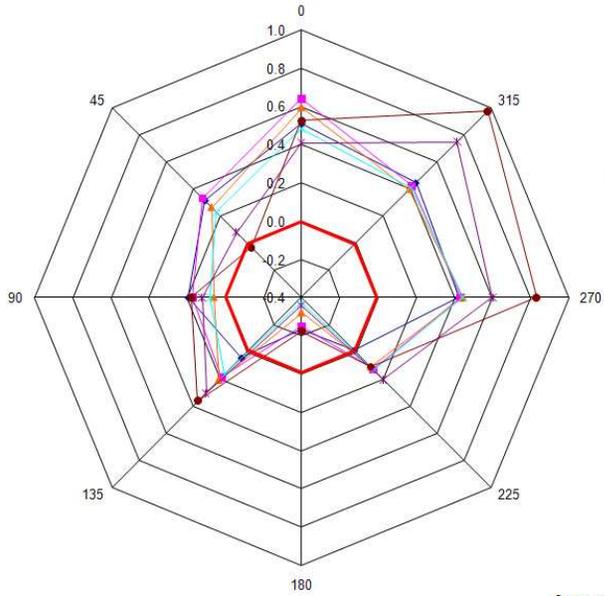
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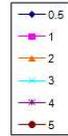
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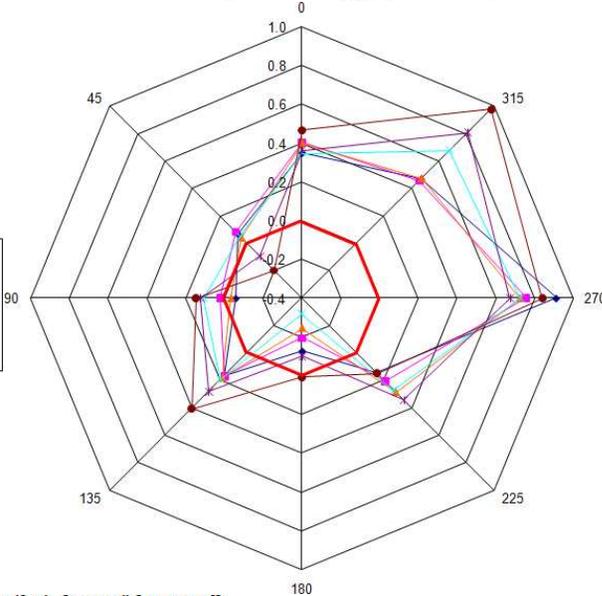
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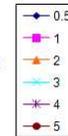
Position on screen up from toe (feet)



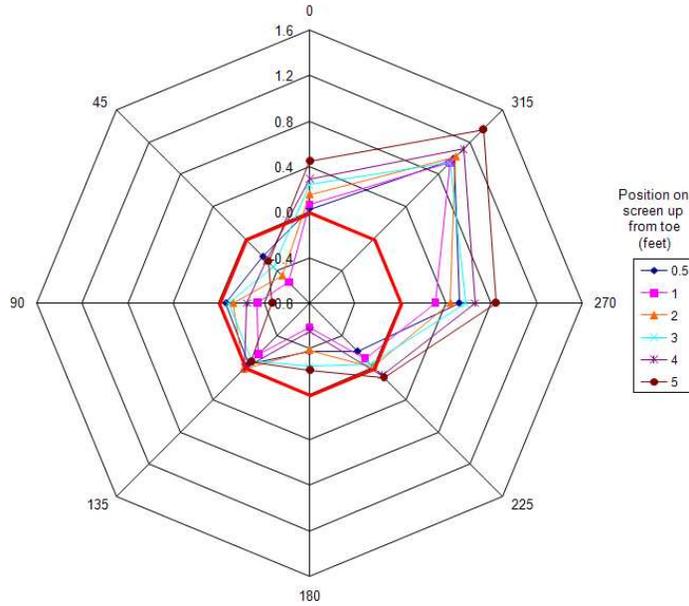
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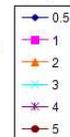
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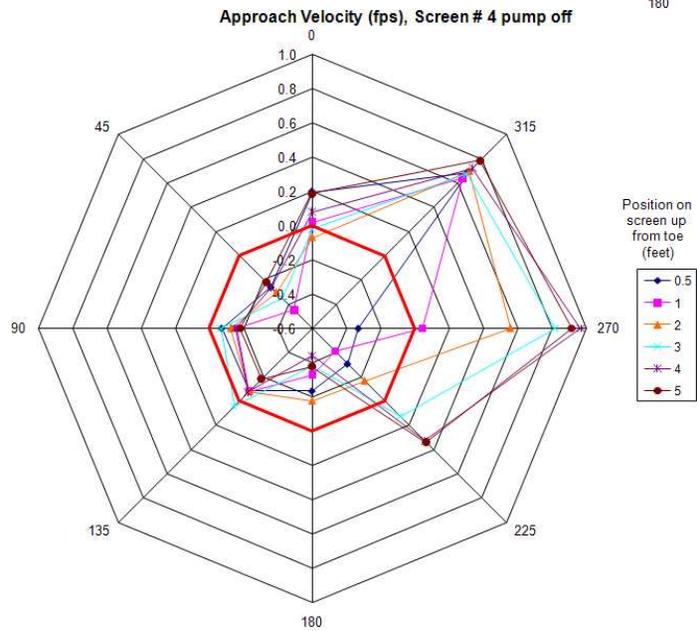
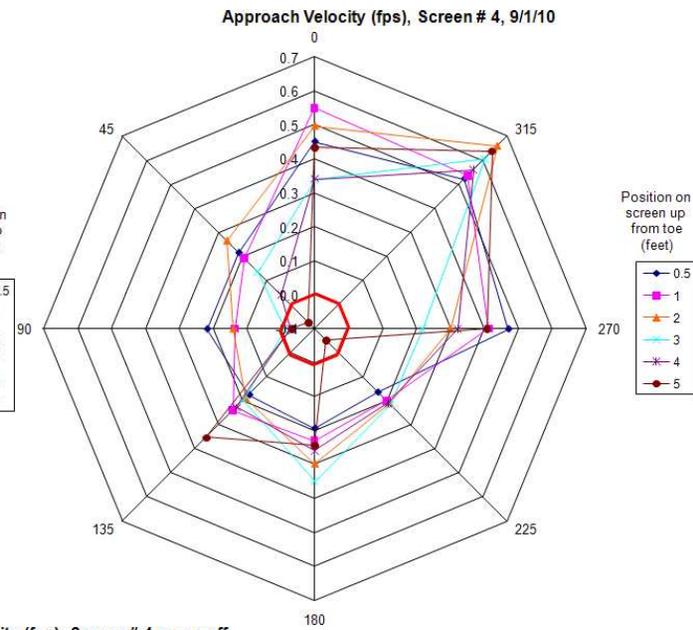
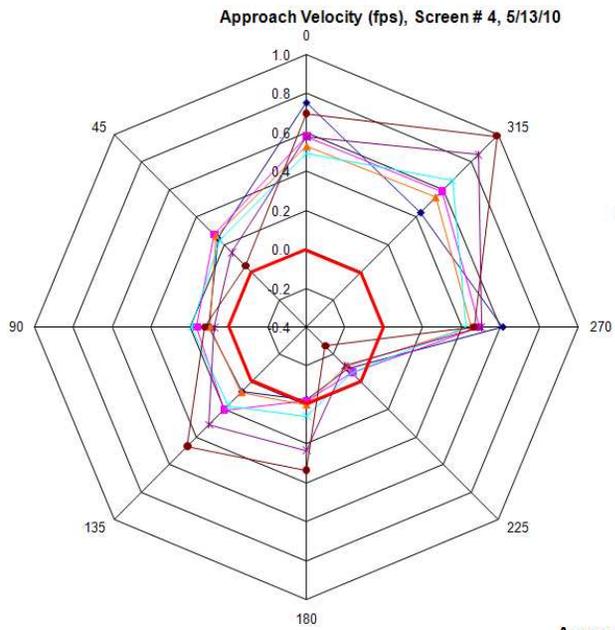


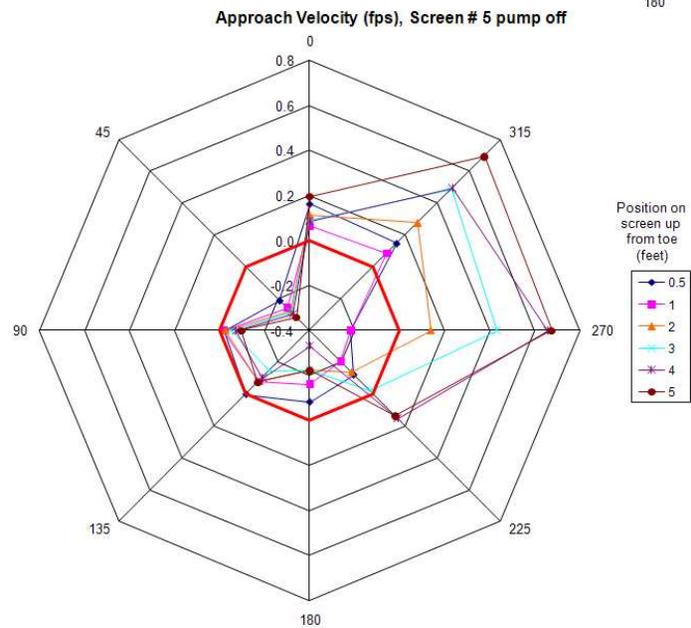
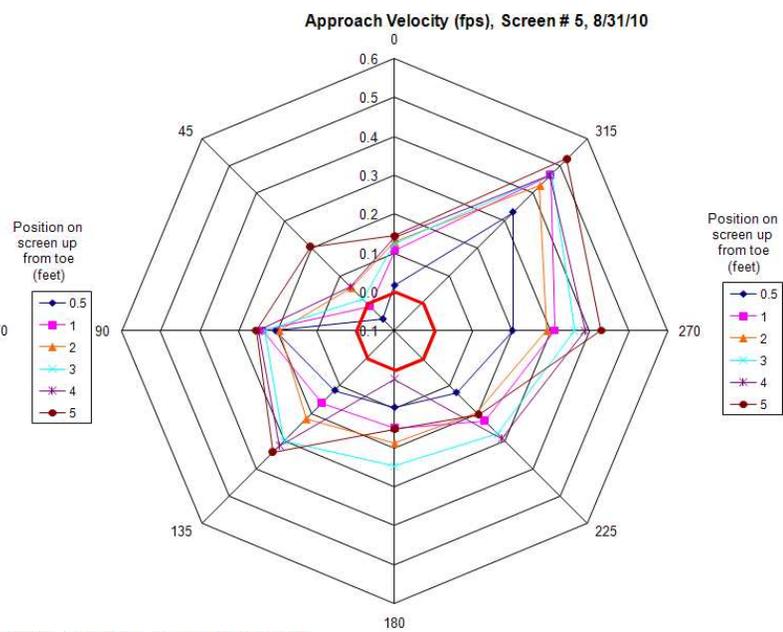
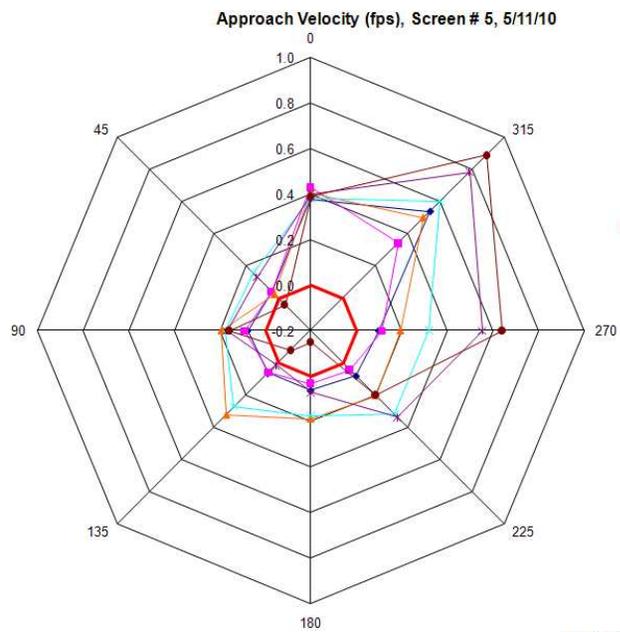
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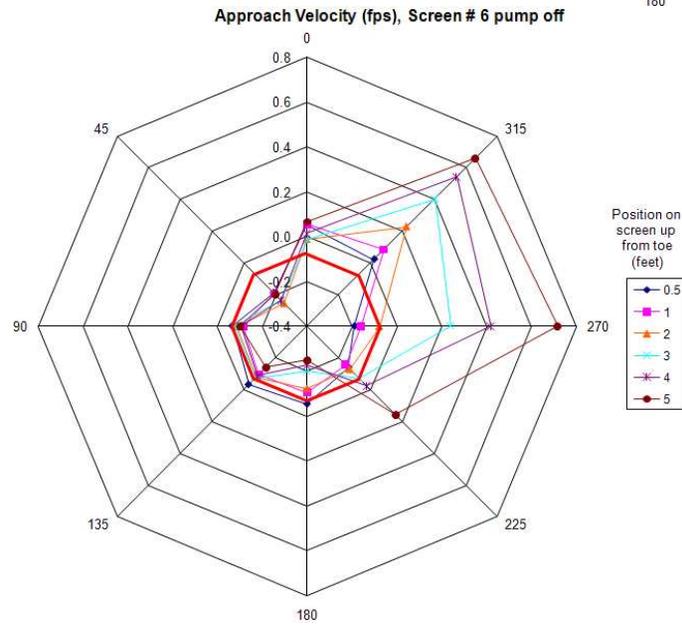
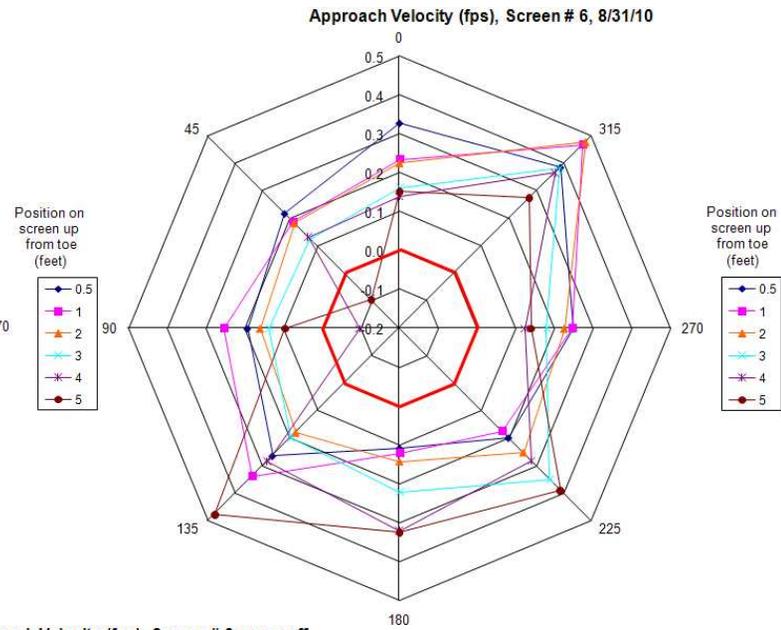
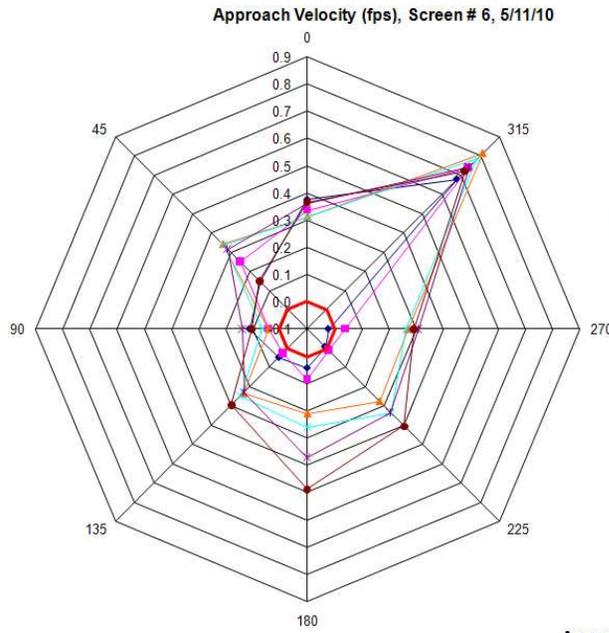


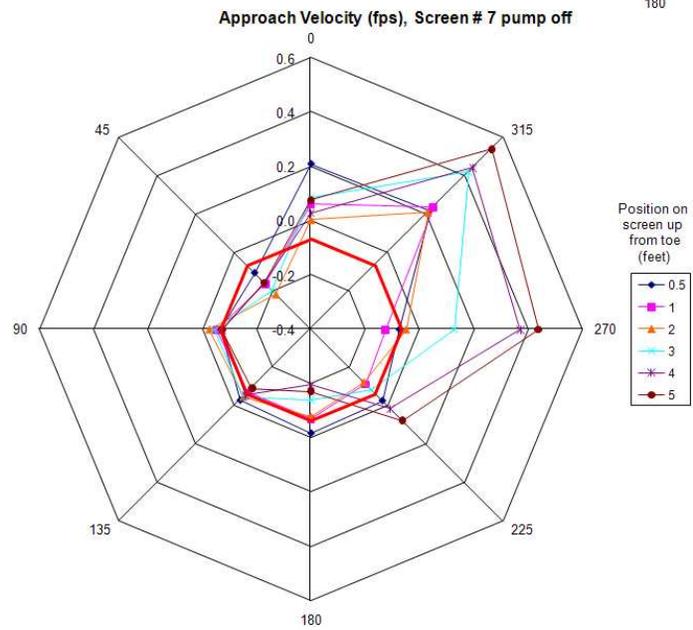
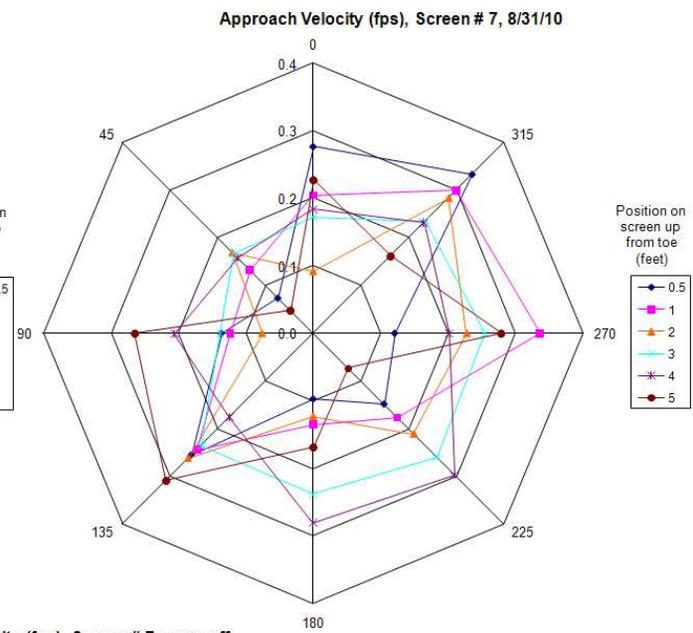
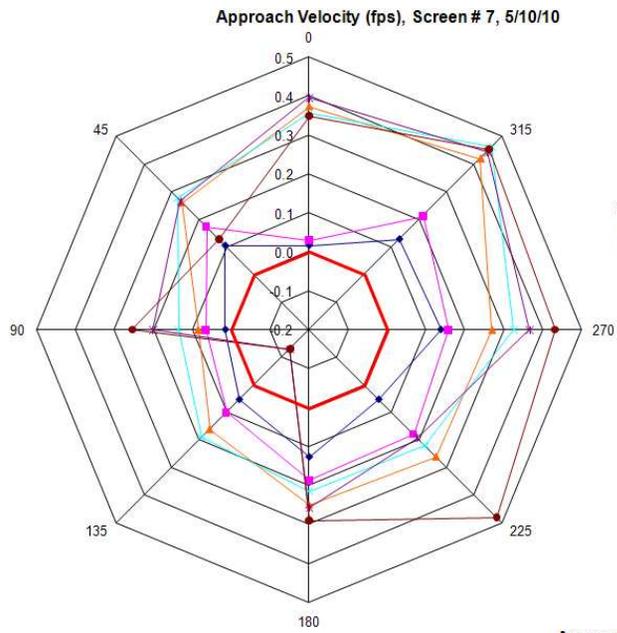
Position on screen up from toe (feet)



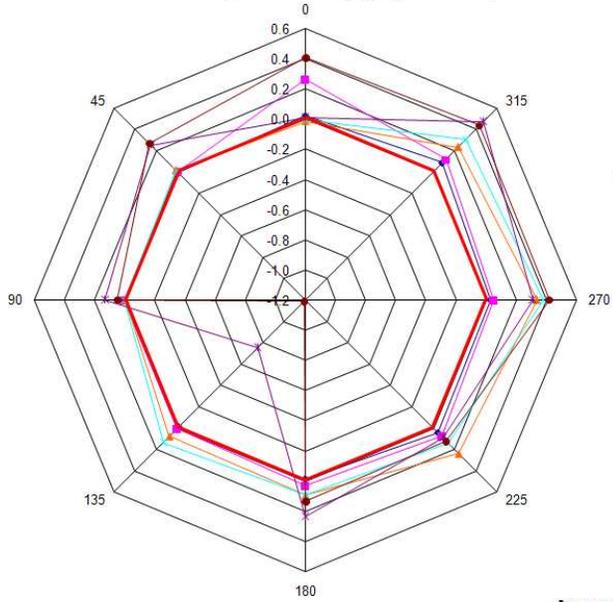




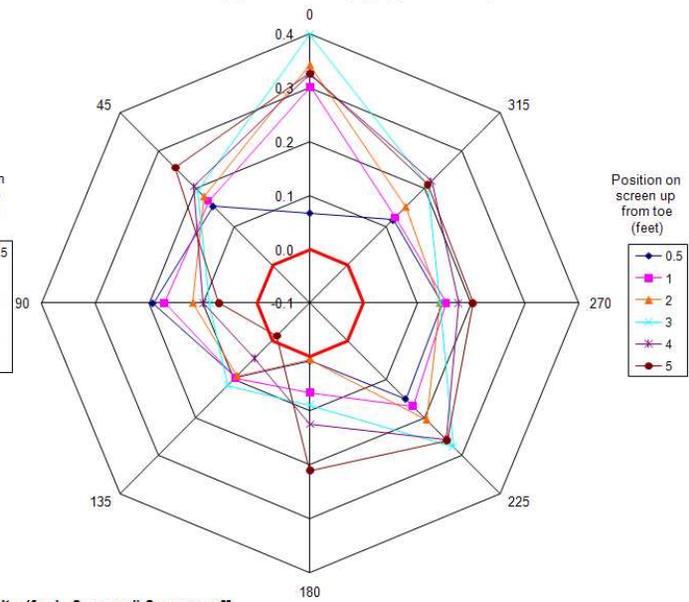




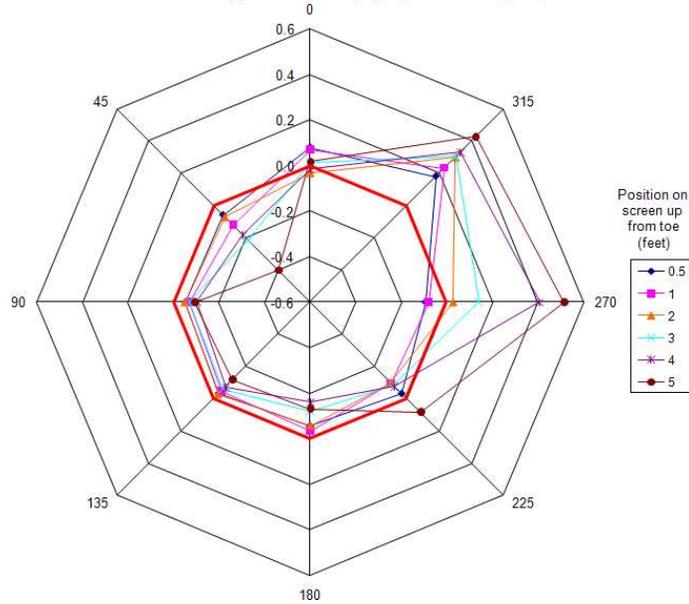
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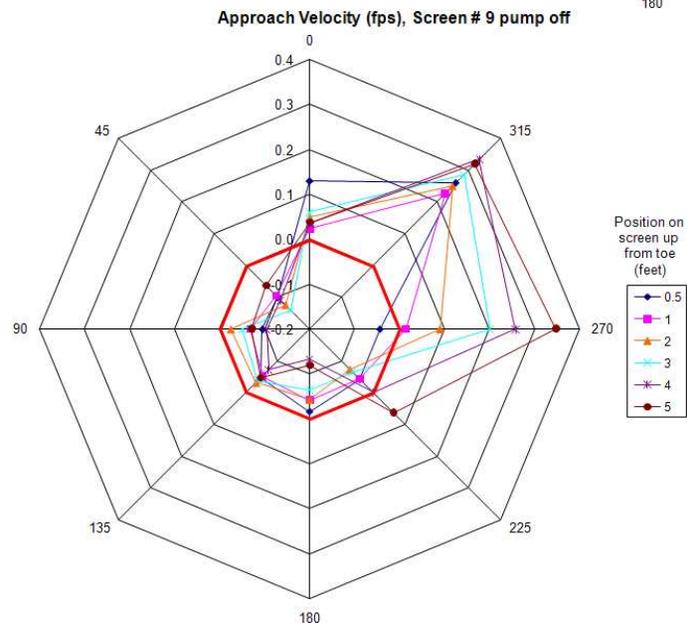
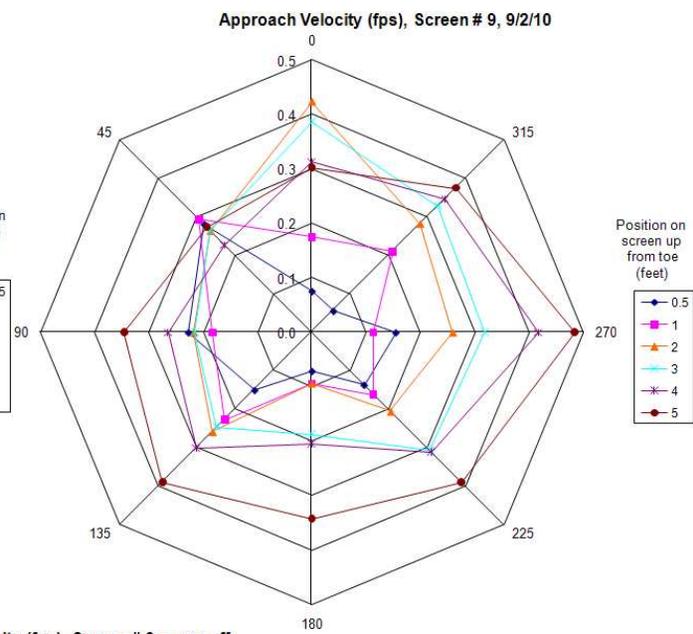
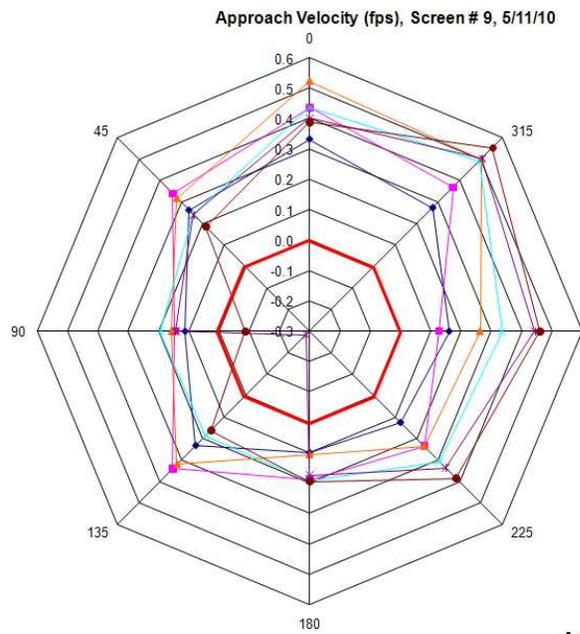


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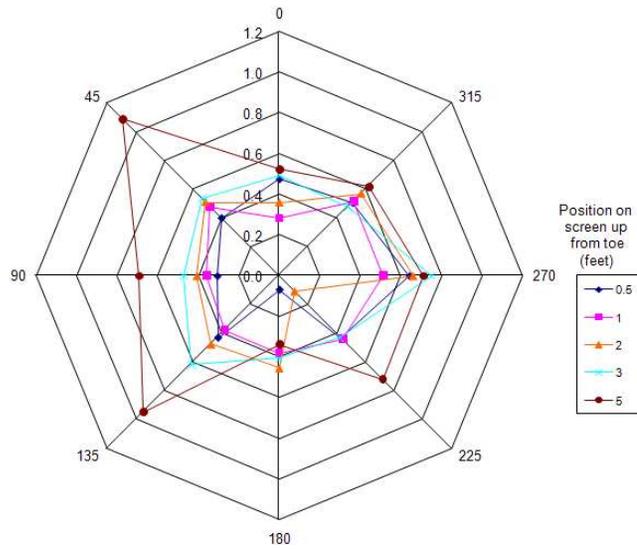


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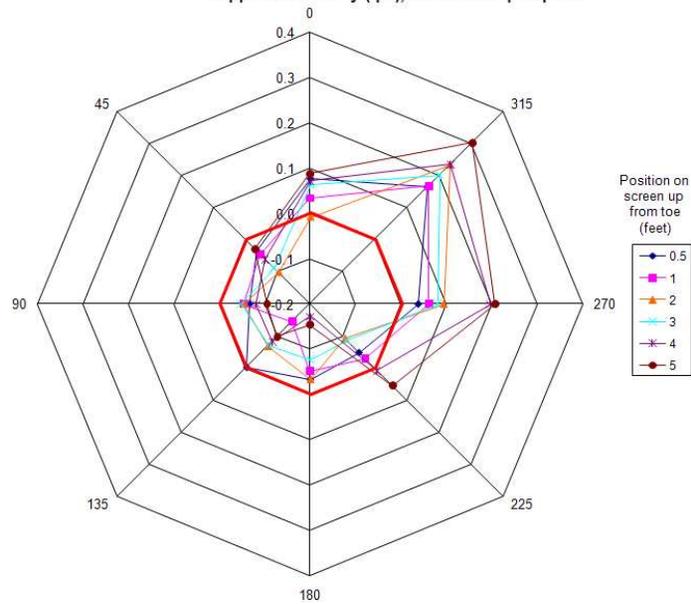


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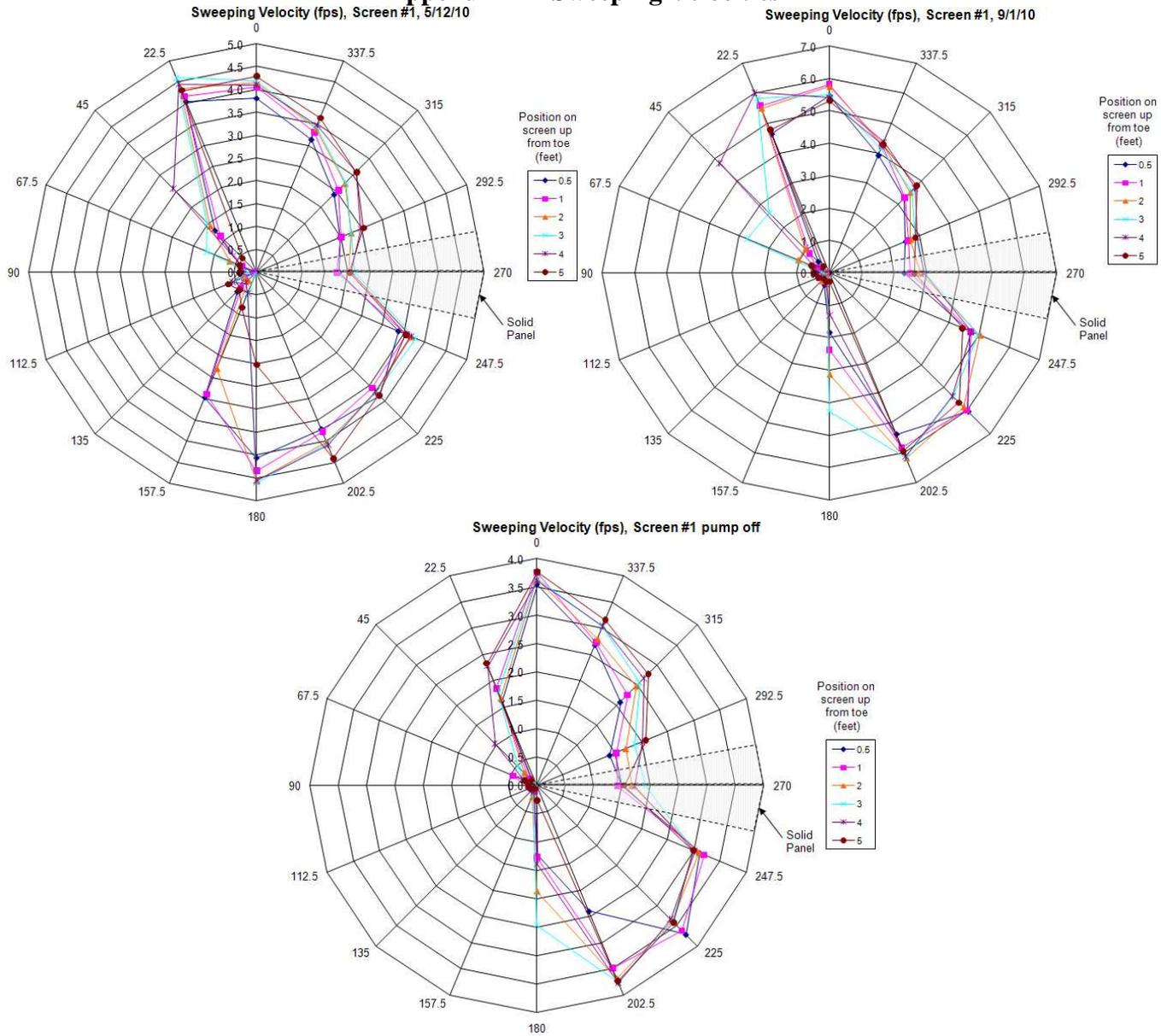


Pump 10 was out of commission on 8/31-9/2/10

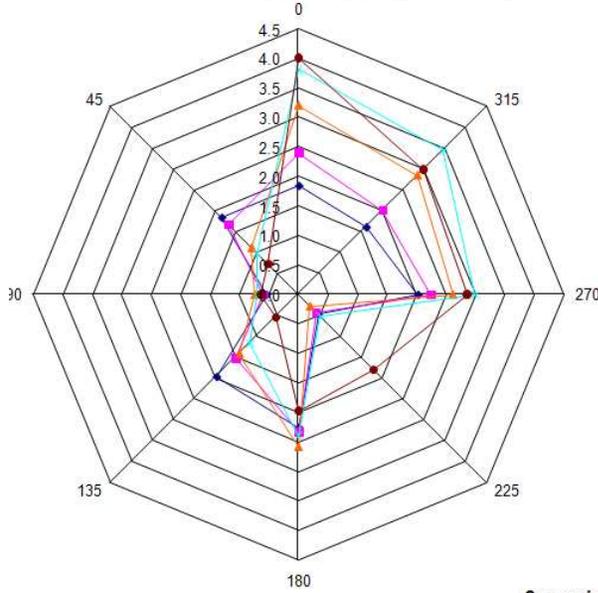
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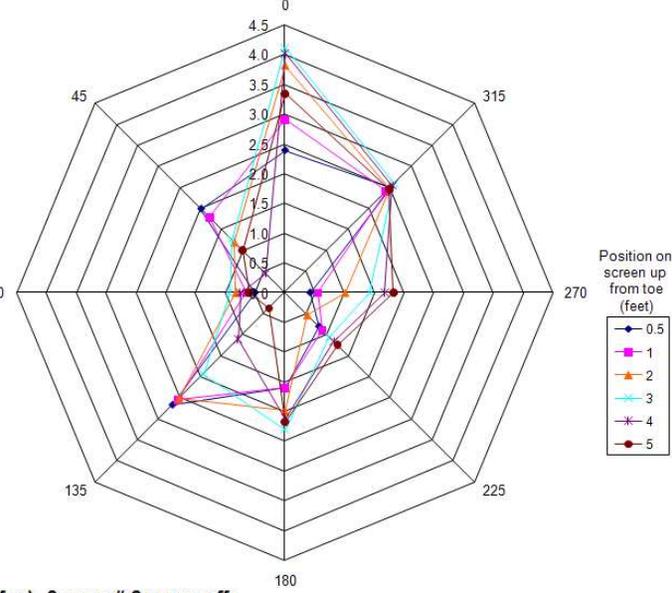
Appendix B – Sweeping Velocities



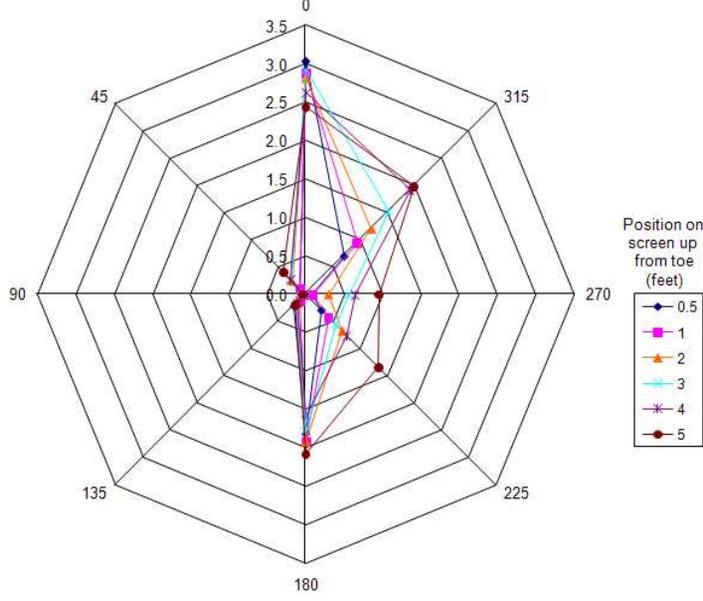
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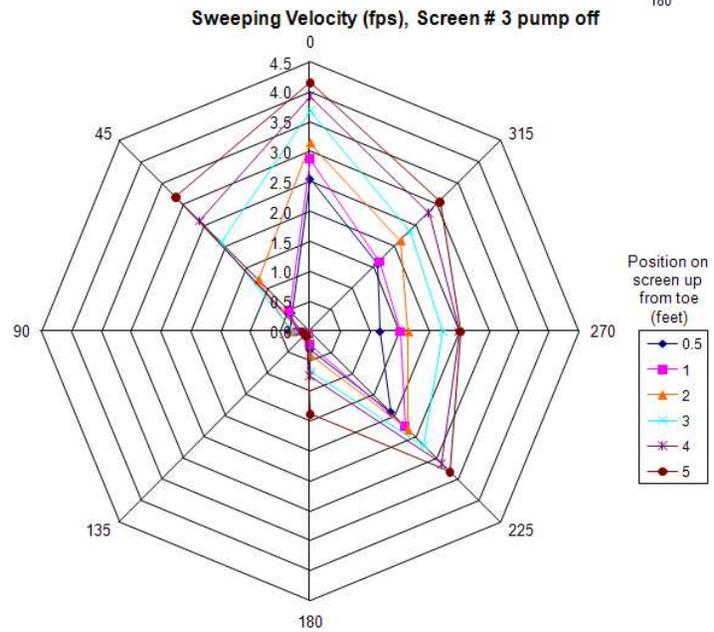
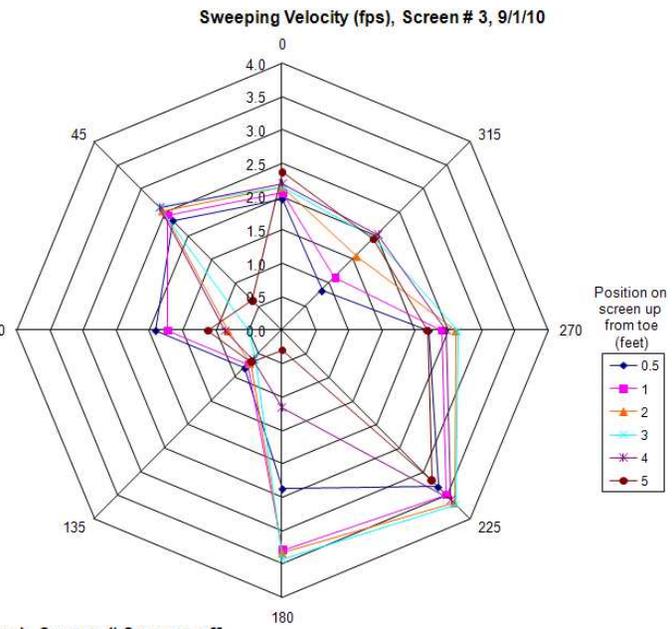
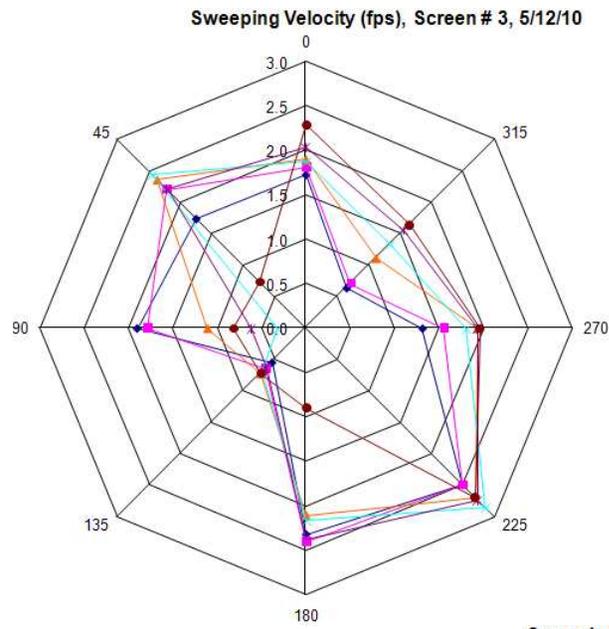


Sweeping Velocity (fps), Screen # 2, 9/1/10

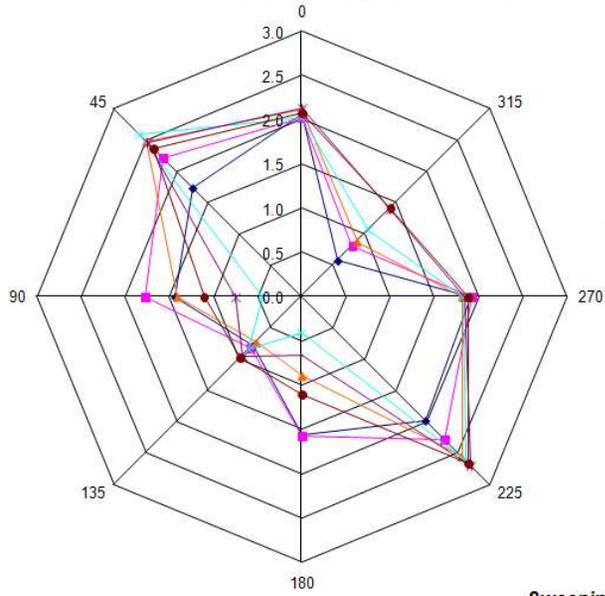


Sweeping Velocity (fps), Screen # 2 pump off

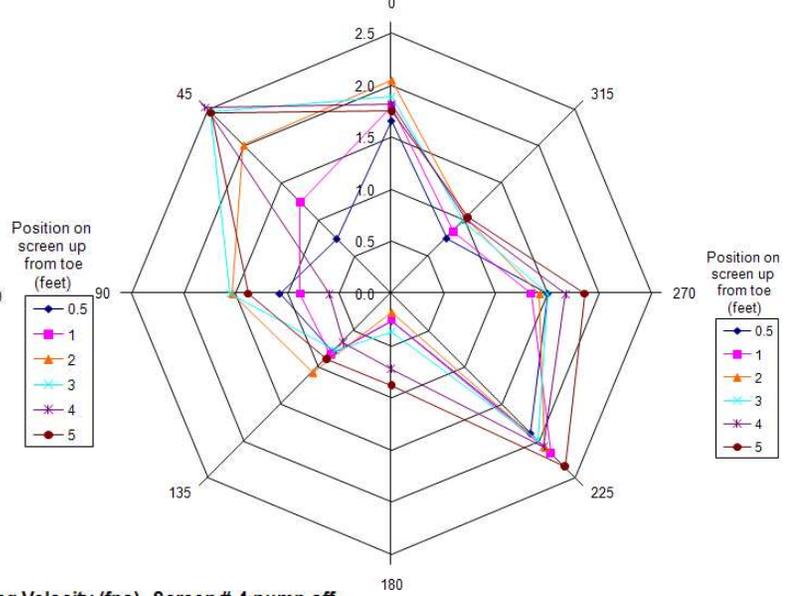




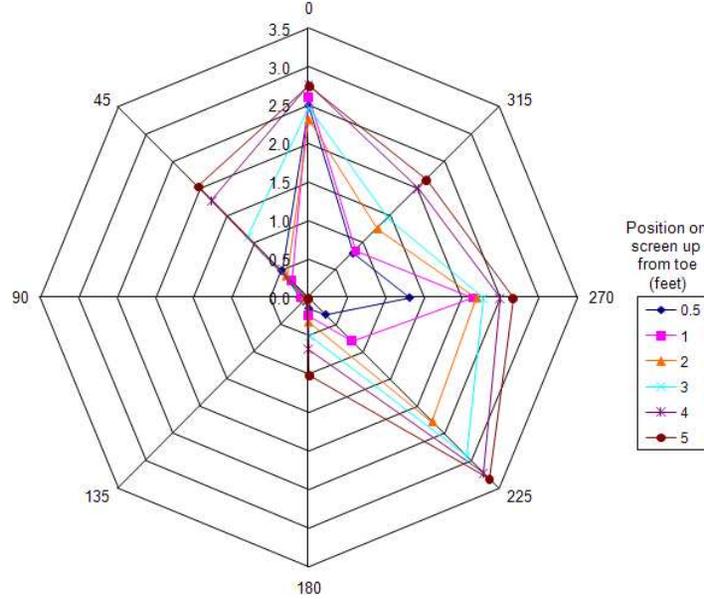
Sweeping Velocity (fps), Screen # 4, 5/13/10



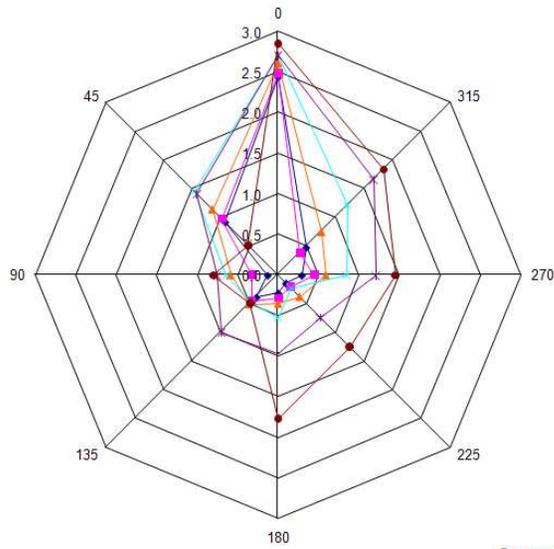
Sweeping Velocity (fps), Screen # 4, 9/1/10



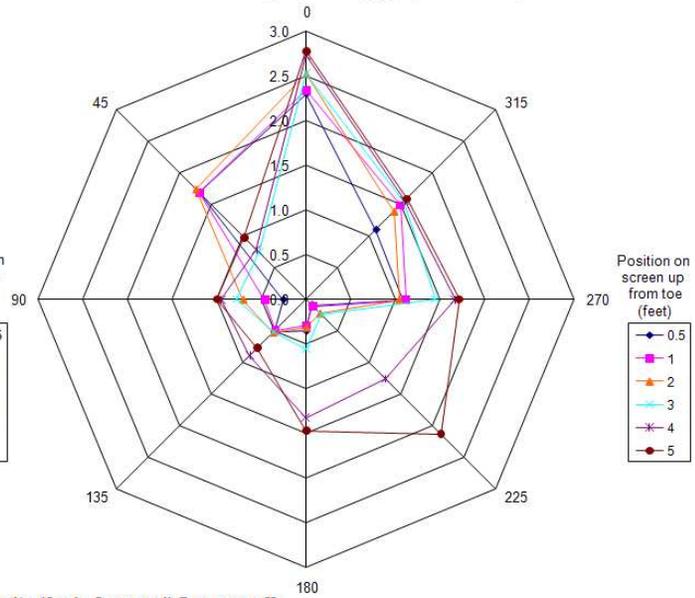
Sweeping Velocity (fps), Screen # 4 pump off



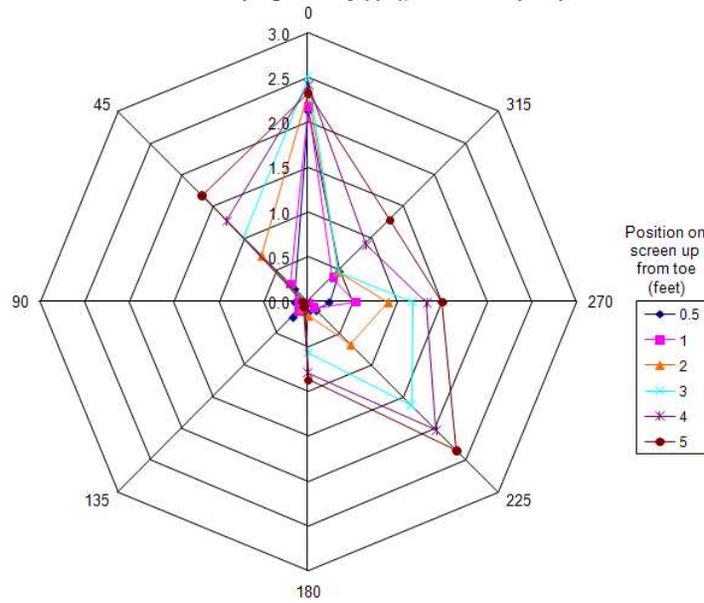
Sweeping Velocity (fps), Screen # 5, 5/11/10

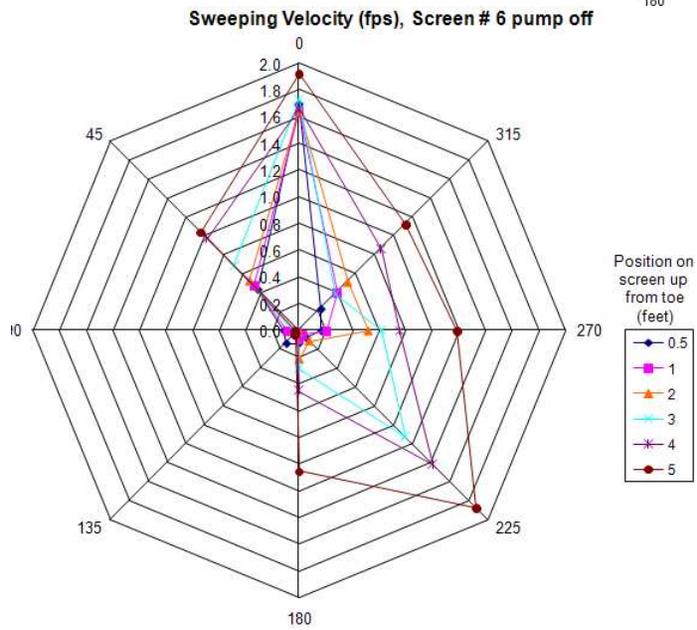
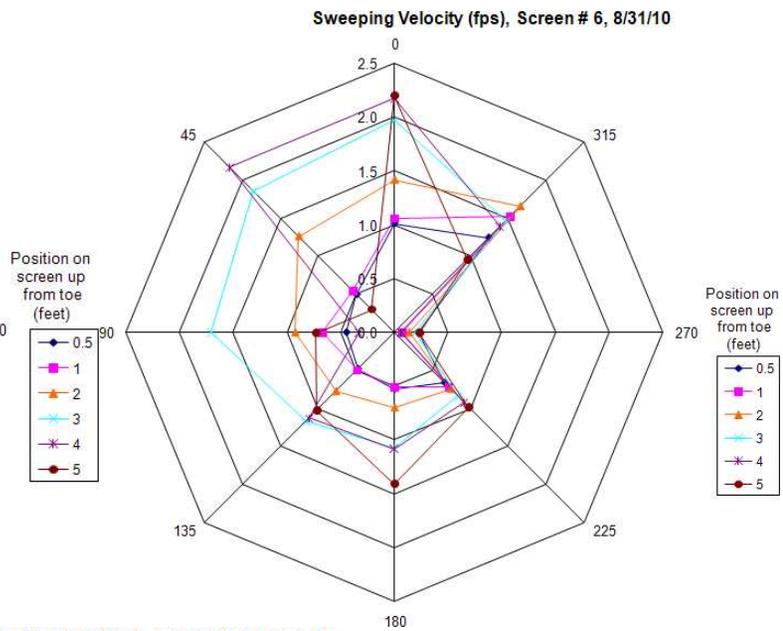
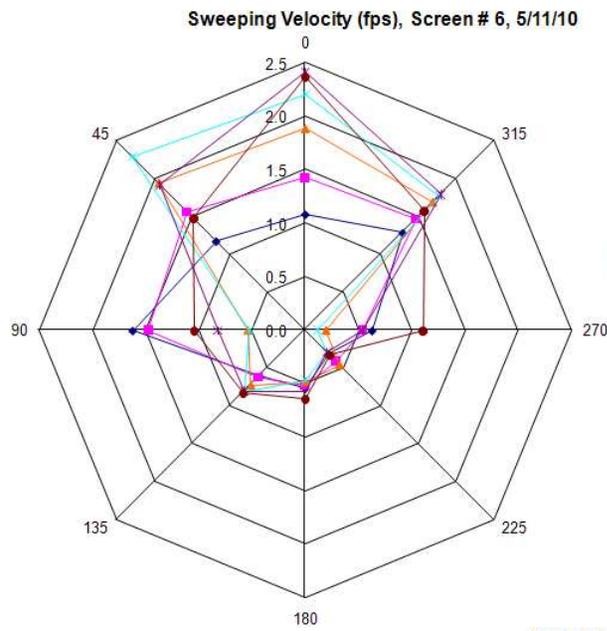


Sweeping Velocity (fps), Screen # 5, 8/31/10

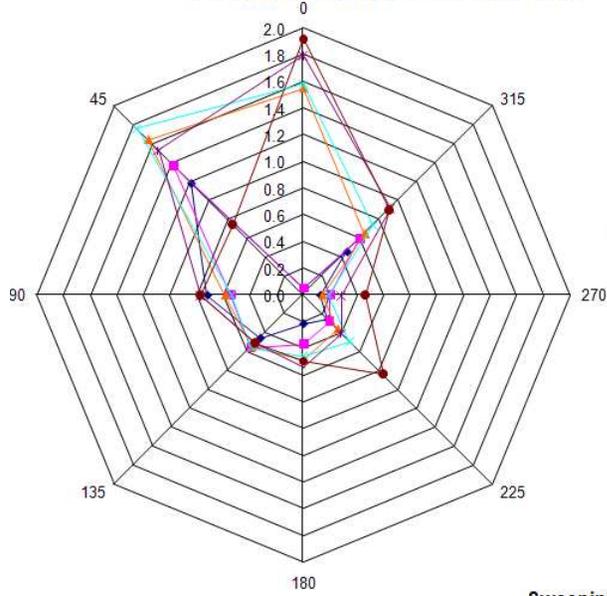


Sweeping Velocity (fps), Screen # 5 pump off

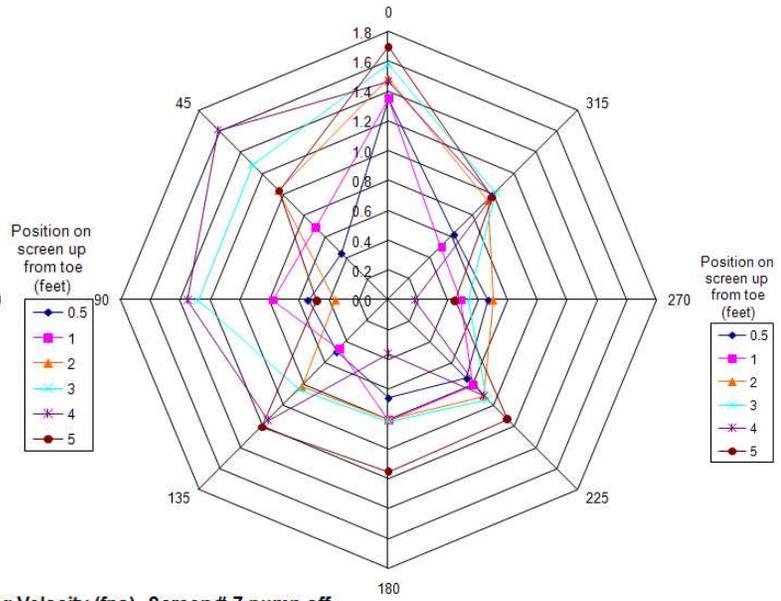




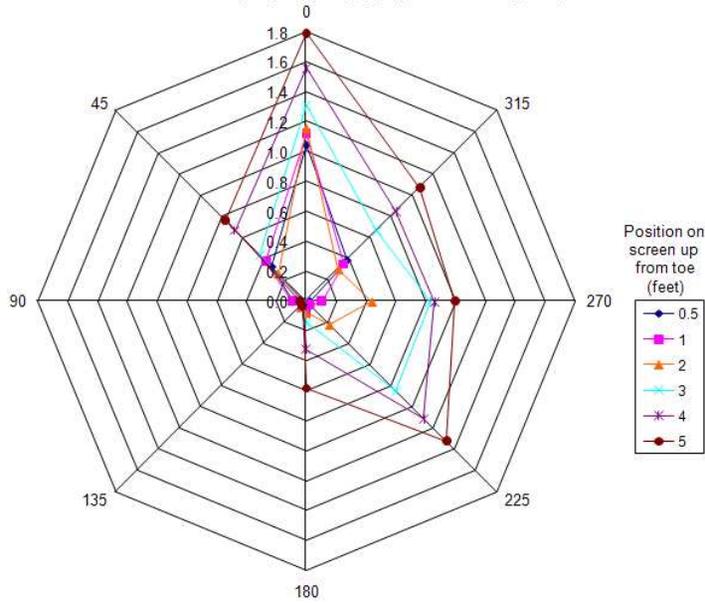
Sweeping Velocity (fps), Screen # 7, 5/10/10

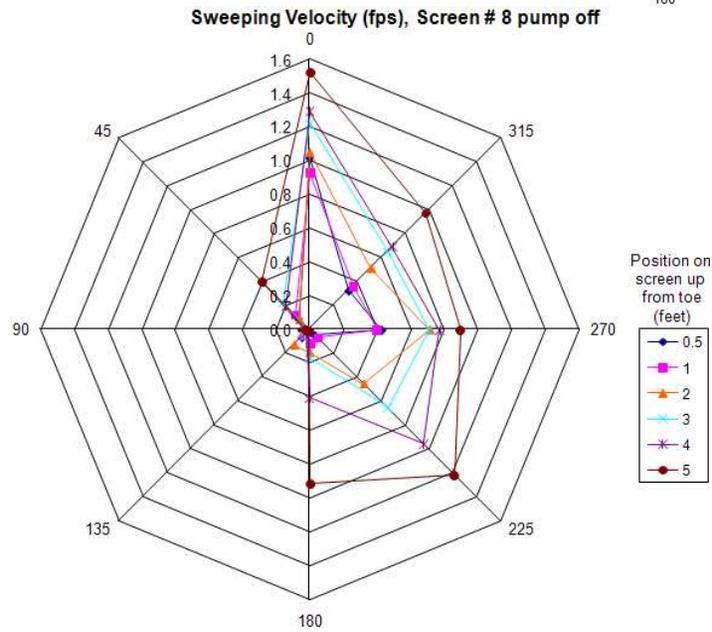
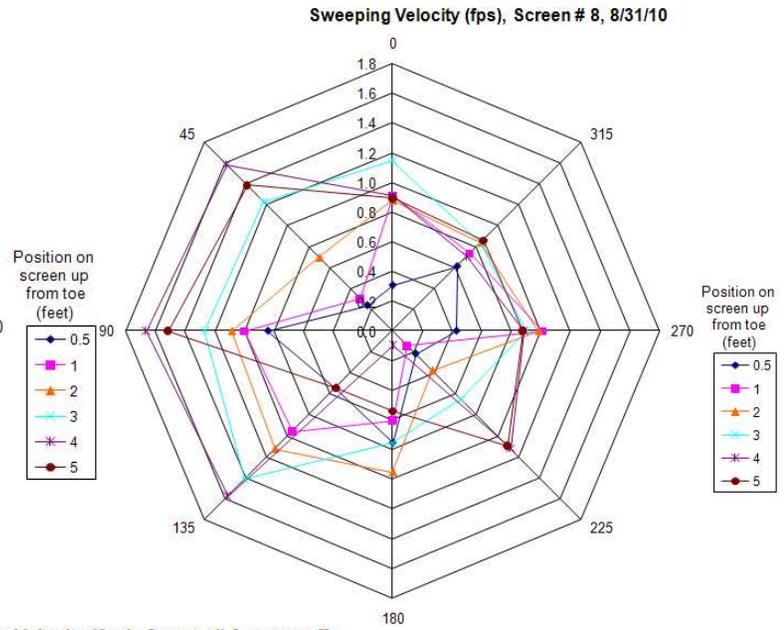
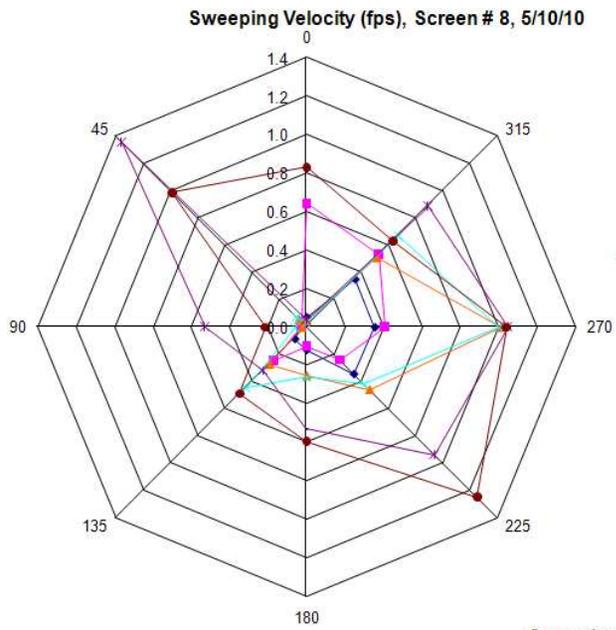


Sweeping Velocity (fps), Screen # 7, 8/31/10

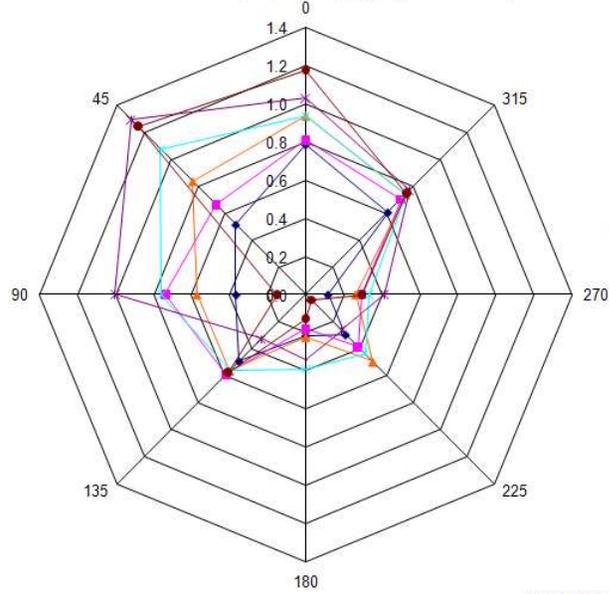


Sweeping Velocity (fps), Screen # 7 pump off





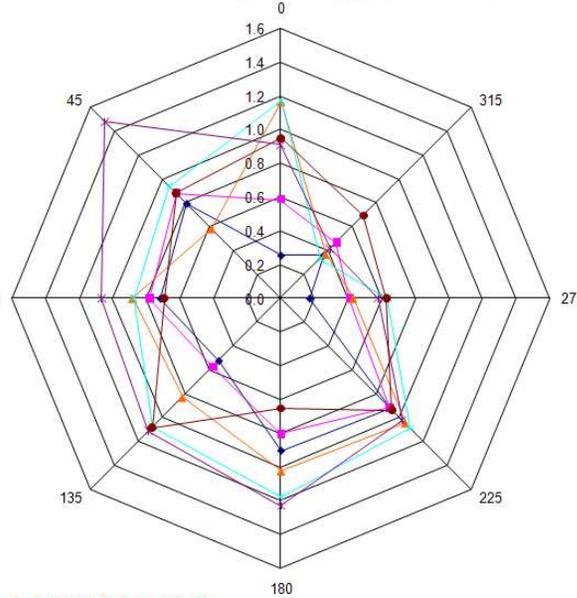
Sweeping Velocity (fps), Screen # 9, 5/11/10



Position on screen up from toe (feet)

- 0.5
- 1
- 2
- 3
- 4
- 5

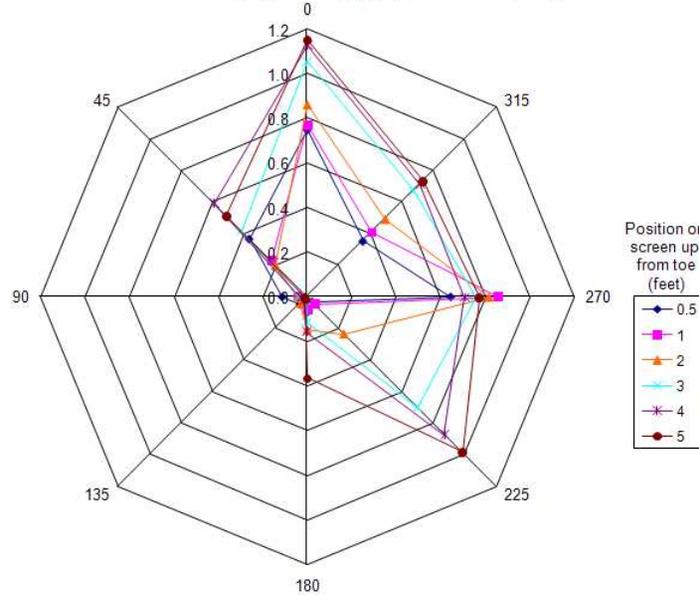
Sweeping Velocity (fps), Screen # 9, 9/2/10



Position on screen up from toe (feet)

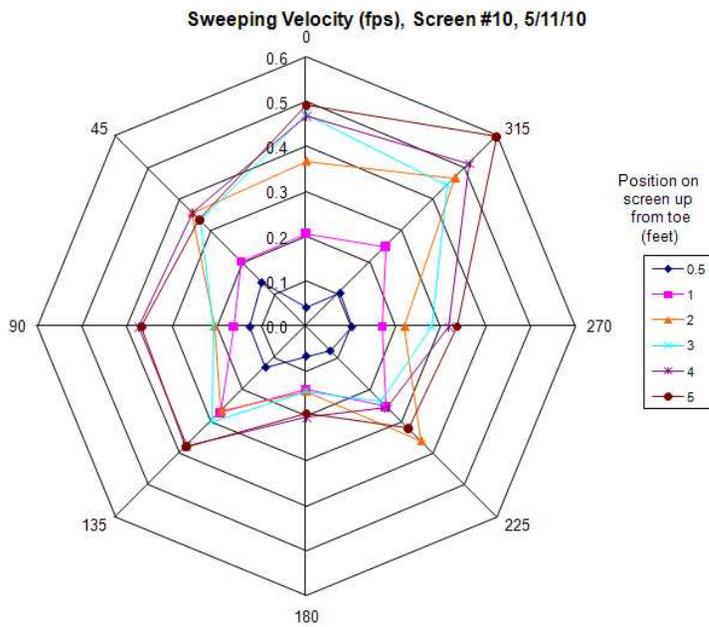
- 0.5
- 1
- 2
- 3
- 4
- 5

Sweeping Velocity (fps), Screen # 9 pump off



Position on screen up from toe (feet)

- 0.5
- 1
- 2
- 3
- 4
- 5



Pump 10 was out of commission on 8/31-9/2/10

