INVESTIGATING THE EFFECTS OF SHUTTLE DISPLACEMENT ON LOOM PERFORMANCE

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Jesse Willard Ellington

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SUMMARY

Experiments to date have failed to produce a simple system of reading out shuttle velocities in a loom weaving fabric. The primary reason for that shortage is that industry has no pressing need for such, so there is a consequent lack of pressure to produce one.

The purpose of this study was to attempt to plot shuttle displacement against time throughout one or more picks and to correlate the findings with loom operation parameters and weaving performance. Within that framework it has been partly successful.

By using two TV cameras, a special effects generator, and a television tape recorder, simultaneous images of shuttle position and crankshaft position have been positioned on single tape frames that make possible reading both parameters on a single monitor. Two strobe lights connected to the loom camshaft supplied the illumination to the crankshaft's graduated (in five degree intervals) handwheel and the inch marks on the loom boxes and hand rail.

By using the crankshaft rotational speed as a base for average time (one degree = 0.000925025 seconds at 180 revolutions per minute) and plotting the distance the shuttle moved from a reference point in time, usually zero at the 90- and 95-degree crankshaft positions that marked the beginning of the picking cycles, successive readings were taken on successive picks until a plot could be made.

The experiment establishes that markings could be made on the loom hand rail or boxes as permanent check points for each loom width and speed.

These markings, if made judicially, would allow a strobe light to be used to check shuttle position before, during, and after the shuttle meets the warp shed. The loom could be set to pick by Draper gauge specifications instead of using a graduated handwheel (most looms are not so equipped) as the pick reference point.

Certain weaving parameters other than shuttle position at a point in time plainly showed under the strobe light. The shuttle never described the same flight pattern twice; it always left the left side with its nose slightly upward and departed the right side with its nose slightly downward.

CHAPTER I

INTRODUCTION

To the textile operating executive, who thinks of shuttle velocity in terms of where the shuttle must be at any point in the weaving cycle, shuttle velocity per se is academic. If the shuttle arrives at the protection point in ample time, it is traveling fast enough.

There is no simple, portable instrument nor system that can be set quickly to a loom to read out shuttle position against crankshaft rotation. Stroboscopic lighting is most useful in making visual checks of shuttle position and attitude, but it is not widely used. The nature of loom performance, and the presence of a sheet of warp yarns above and below the shuttle during a great portion of its flight add to the difficulty of producing read-out systems.

The mere presence of the top shed, which may vary in density from sheerness to opacity, limits the use of visual sighting techniques. Twills with a high cover factor, for instance, may be woven on cam looms and face up. And in such cases, management sensibly often elects to lower each harness in turn for the required number of picks rather than lift a greater number of harnesses with their accompanying sheds and greater tensions. A 3/1 twill requiring near-maximum sley (a k_2 approaching 28 for cottons) woven thusly always has 75 percent of its warp ends in the top shed while the shuttle is in the cloth, a yarn density that almost hides the shuttle from view and sorely limits the accuracy of reflective readings from the shuttle.

Still, Perner (1) describes such a system and pronounces the reflection principle adequate. He fixed a reflection ring to the filling quill, rotated it 180° after each pick to get a reading on the next pass, and plotted the increments pick by pick.

Szosland (2) charted the curved trajectory of the shuttle flight by mounting a light inside the shuttle and picking up the beam by photo cells. The procedure is lengthy, slow, requires much equipment, and is mostly suited for laboratory research. The cells must be positioned for a reading at any one point, but the system seems to spot faulty shuttle flights instantly.

Ellington (3) examined shuttle behavior photographically in a loom with a warp, an artificial situation, but did not attempt to establish shuttle speeds seriously nor to examine all patterns of shuttle flight for faulty operation.

The Draper Division of North American Rockwell Corporation (4), for several generations builders of automatic looms, has repeatedly addressed itself to the problem, two such attempts being outlined in a letter from Charles Burnham in 1968:

> We addressed ourselves to the problem in 1955, and undertook the design of a crystal-controlled doppler speedometer with coupled operational amplifier for continuous position indication.
>
> The task of reducing a suitable transmitter or transponder to fit into the shuttle with a yarn supply was almost insurmountable at that time, and the shock requirements exceeded the existing technology.
>
> In 1965 a renewed requirement for shuttle telemetry led to development of a miniature solid-state accelerometer based on a tunnel-diode variable oscillator in the FM band. This development, while incomplete, does produce satisfactory continuous velocity

output, but double integration for position is unreliable to date.

> We believe that the intensive accelerometry effort on which inertial guidance is based, gives the best long-term approach to shuttle telemetry, but we recognize that the doppler technique is probably a surer short-term approach for position indication.

Burnham further stated: "...we do not know of any existing continuous-position shuttle indicator that can be operated in a loom weaving fabric."

Recognizing that high-speed photography would be expensive and could record only a few picks, Lord and Hamed (5) made split-image pictures of the shuttle in two positions by inserting a shield between the camera lens and the shuttle and using two flash lamps. Using two lamps allowed them to be fired in quick succession without being bothered with the recovery time each lamp required. A microswitch driven from the cam shaft triggered each lamp; a synchronous motor rotated a timing disc within the picture area to record the elapsed time between flashes. The timing disc eliminated any effect a change of loom speed would have, while the shield or divider prevented the light from one lamp from exposing the film area reserved for the other lamp. They used a sequential camera that advanced one frame of film per pick. And they also recognized that variations occurred from one pick to the next from the same side of the loom and established a correlation between late picks and strong picks.

In a related research venture Lord (6) studied the differences in alacrity (much the same as stiffness) between the pick motions of a loom and found that alacrity was not constant. By double differentiating the displacement curve of the picking phase he showed that the load on the picker during acceleration is anything but smooth. Picking seems to progress in a series of surges.

The textile industry still produces the bulk of its fabrics on the fly-shuttle loom, whose innermost secrets still defy direct reading. The loom, which remains relatively unchanged since antiquity, still is composed of three basic motions: (1) shedding; (2) picking; and (3) beating up. It still uses a simple picker stick to sweep the shuttle from the boxes, still sends that shuttle across a platform rocking several inches at right angles to the shuttle's course, still sends the shuttle between sheets of warp yarn, still catches it in a box that controls a protector motion, and still sends it back just as fast.

This is a proposed attempt to plot shuttle displacement against time throughout one or more picking cycles and to correlate the findings with loom operation parameters and weaving performance.

CHAPTER II

INSTRUMENTATION AND EQUIPMENT

The loom used for all these readings was a Model-E Draper automatic fitted with a blue-denim warp and cammed to produce a 2/1 twill. Effective loom width was 38 inches; cloth width was 30 inches; loom crankshaft speed was 180 rpm. Other equipment included:

Two Concord Model TCM-20 Television Cameras/Monitors fitted with
f 1.8, 25-100mm Vidicon Zoom Lenses
One Model VTR 620 Video Tape Recorder, Concord
One Model WV 600P Special Effects Generator, Panasonic
One Model 1531 A Strobotac, General Radio Company
One Model 1535 B Contactor, General Radio Company
One Model 1532-D Strobolume, General Radio Company

The Draper loom was equipped with a spring-top harness motion that used cam-shaped top harness sheaves to exert maximum force to the harnesses as they neared the top of their shedding, where tension is most needed. Its shuttle was 16¼ inches long and weighed 1.25 pounds when carrying a half-empty filling bobbin. The parallel motions were the conventional foot-and-shoe type, now largely being replaced by the more accurate link-types. Picker sticks were hickory, not laminated; check straps were flat cattle-hide pieces with slotted holes at each end for adjustment. A simple finger could be adjusted against them to change tension.

The loom was used without drag rolls, and the pick gear was changed from 42 to 25 to reduce the load on the loom and to lessen chafing in an aging warp. Filling count was changed from coarse 7s to a much finer 35s to help further in reducing speed loss during the beat-up. The loom was stripped of its filling magazine and filling stop motion to get those assemblies out of the line of camera sight. The warp stop motion was left intact, though it was rewired for the 220-volt power supply to the loom motor. A damp cloth spread over the warp behind the drop wire banks supplied adequate humidity to the heavily sized 6.7s warp yarns.

When ready for the speed studies, the loom represented a worn but serviceable unit fairly typical of many such looms operating today--maintained neither poorly nor superbly. Furthermore, its inherent lack of power and speed rendered it especially sensitive to slight changes in box, harness, and power settings, all of which affect shuttle speeds. In that condition it ran at a steady 180 picks per minute.

CHAPTER III

PROCEDURE

The Model-E loom was fitted with a handwheel graduated into five-degree increments with ten-degree intervals stamped into the metal. The readings were thus 10 through 360° with the final figure also representing the zero point. The back box plates and hand rail were marked every inch as reference points. Total shuttle flight from each box to rest was 66 inches.

The loom was originally timed to pick at 95° from both boxes, but a faulty pick motion forced retiming the left side to pick from 90°. Harness leveling was set at 2.25 inches.

One TV camera was leveled at the handwheel and its pointer, the lens zoomed in to enlarge the image greatly--about 35° of the top arc of the wheel were visible on the 23-inch monitor screen. The second camera was tripod-mounted and positioned high and in front of the loom lay. The lens was zoomed only enough to include one shuttle length in the field of view when reading the flight into and out of the box. The field of view was adjusted as needed when reading through the top warp sheets. Both cameras were connected to the special effects generator, which in turn was connected to the video tape recorder. A single monitor was connected to the tape recorder and the generator adjusted to position the hand-wheel image in the upper fourth of the monitor, with the shuttle and handrail images using the bottom three fourths of the screen.

The contactor was magnetically coupled to the cam shaft and connected to the Strobotac, which was set for high-intensity flash and external input signal. The instrument was positioned close against the handwheel pointer and to one side to move it out of camera range.

To the Strobotac was connected the Strobolume, which has a detachable flash tube that can be carried about or secured to a tripod. Set at high intensity, the Strobolume emits 10,000,000 beam candle power. Throughout the experiment the flash tube was hand wielded; and both the strobe units were used as slaves, getting their flashing signals from switch closure within the contactor.

The contactor was adjusted to signal a flash when the crankshaft rotated to the picking point, the "zero" points of 90° and 95°. One person monitored the loom, one operated the camera in front of the loom, and one operated the controls and kept the flash tube directed onto the target.

Readings were taken at the right-hand box for acceleration studies, and while the camera remained in that position the contactor was adjusted throughout a picking cycle to pick up the shuttle as it returned to the box. The camera was relocated to the left of that point and a second set of data collected as the shuttle left the right-hand side. Again the contactor was adjusted through a picking cycle until the shuttle reappeared in view from the left. Only four camera locations were needed for the complete set of data. The four fields of view overlapped slightly, which gave additional check readings. Wider looms would require more camera movement.

All readings into the TV camera were taken in a darkened room. Efforts to make readings in daylight proved fruitless, as there was always a shuttle image crossing the field and quite visible in the ambient light.

The TV cameras gave a lingering image that proved useful in taking the data from the tape. Two persons watched the monitor screen and voiced the readings into a single tape recorder microphone. Later the readings were played back from the voice recordings and committed to paper.

The raw data were plotted onto graphs, distance in inches against the crankshaft degress that were used for time. The readings shown in Figures 1 and 2 start at the 90° (left side) and 95° positions and continue through the full length of the shuttle path. However, the distance from 60 inches onward was omitted from all calculations, as that section of the trajectories involved the loom checking motions.

Accelerations that support the peak velocities were established by reading the curves (Figures 1 and 2) for the angles coinciding with the points of greatest velocity and using the formula:

$$a = 2S/t^2.$$

Further charts (Figures 3 and 4) were prepared to examine more closely the distances and times involved with acceleration. The loom was turned over by hand with the shuttle fully boxed and the crankshaft readings taken every five degrees. Those time elements were plotted against the distances through which the shuttle moved with each five-degree increment of the cam shaft. Those plots are labeled "nominal" in the figures and were used in part to establish that the picking cycles actually began with the 90° and 95° positions. Plotted alongside those nominal curves are the actual movement curves drawn from the data observed.

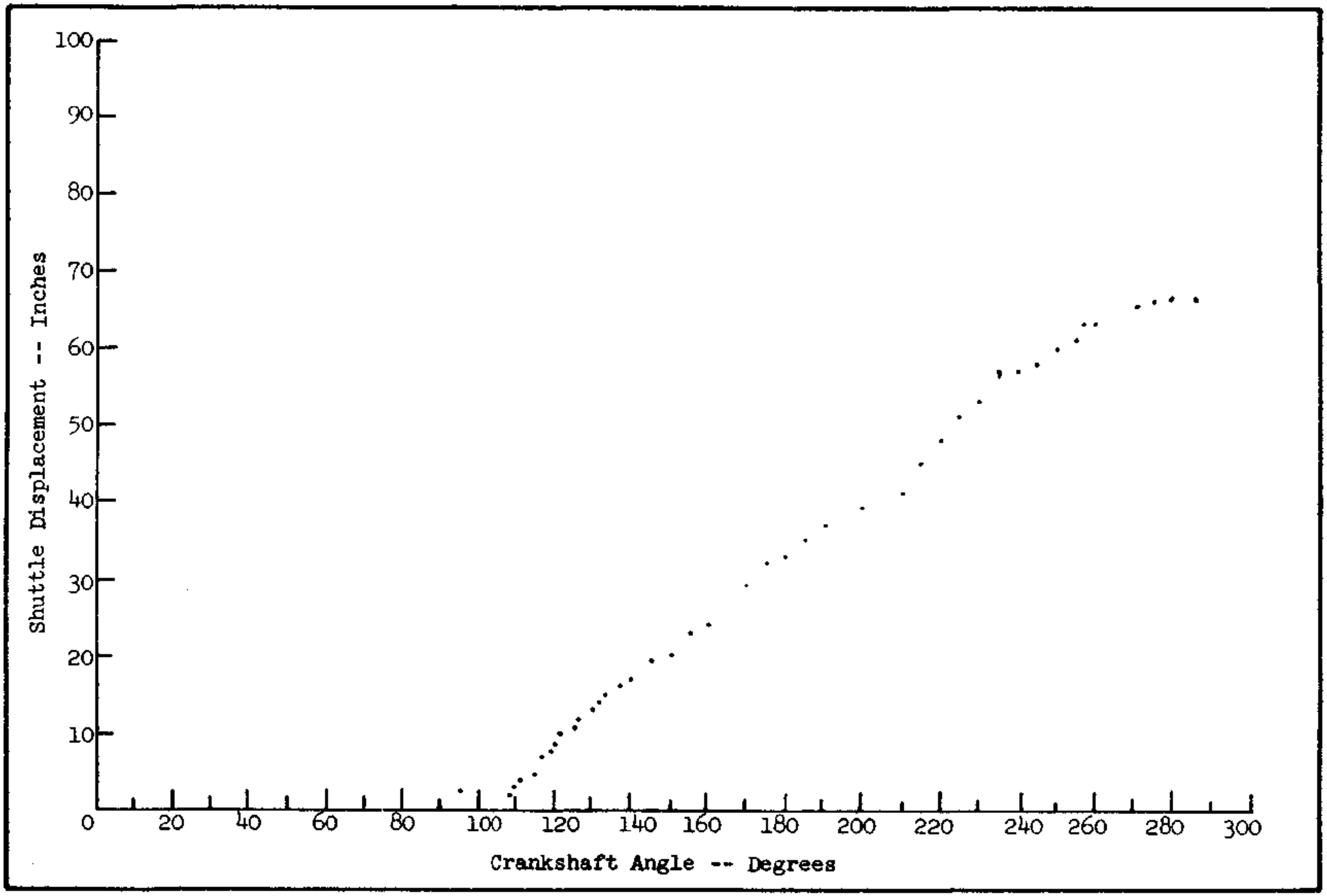


Figure 1. Successive Shuttle Positions Reading from Left-Hand Box

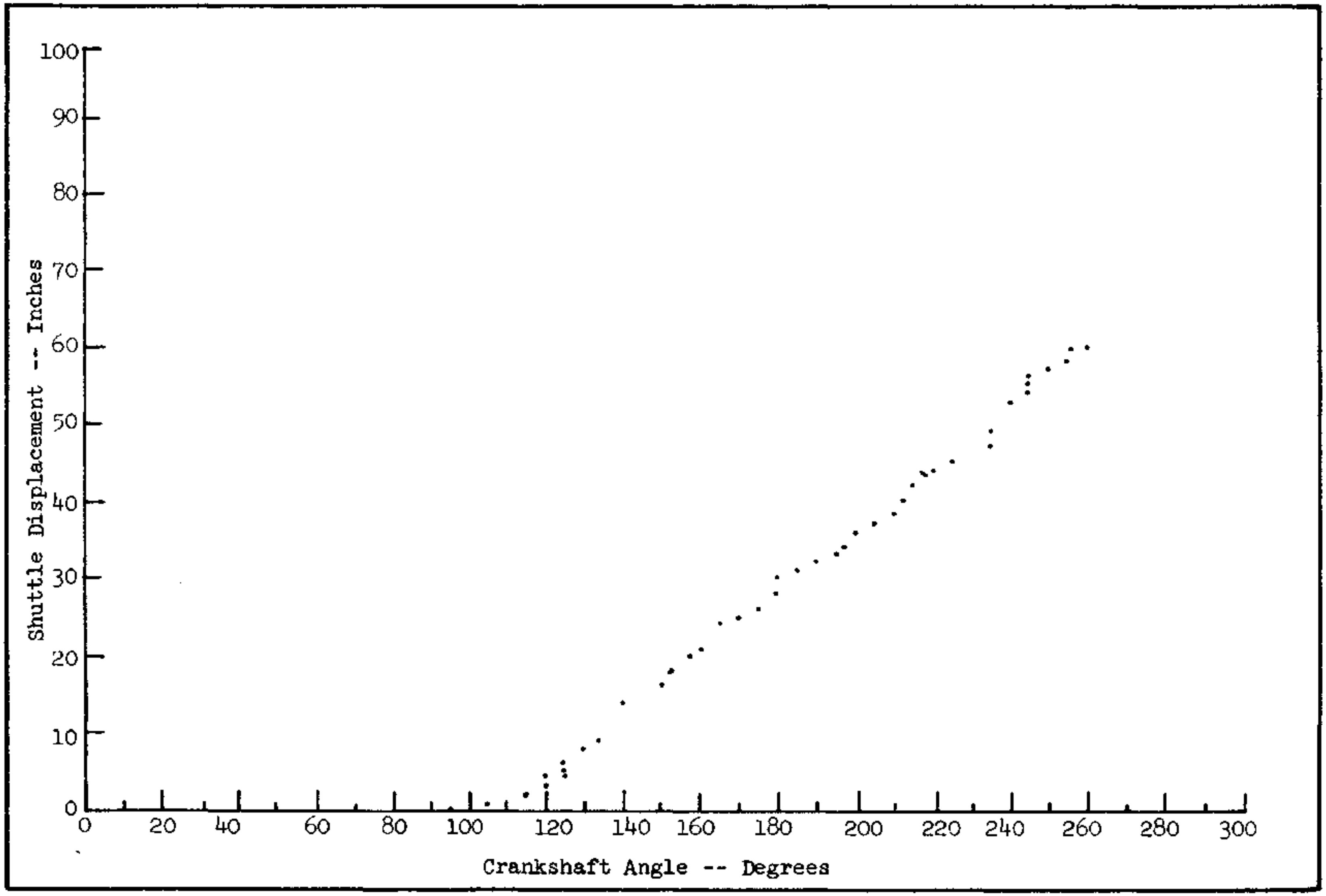


Figure 2. Successive Shuttle Positions Reading from Right-Hand Box

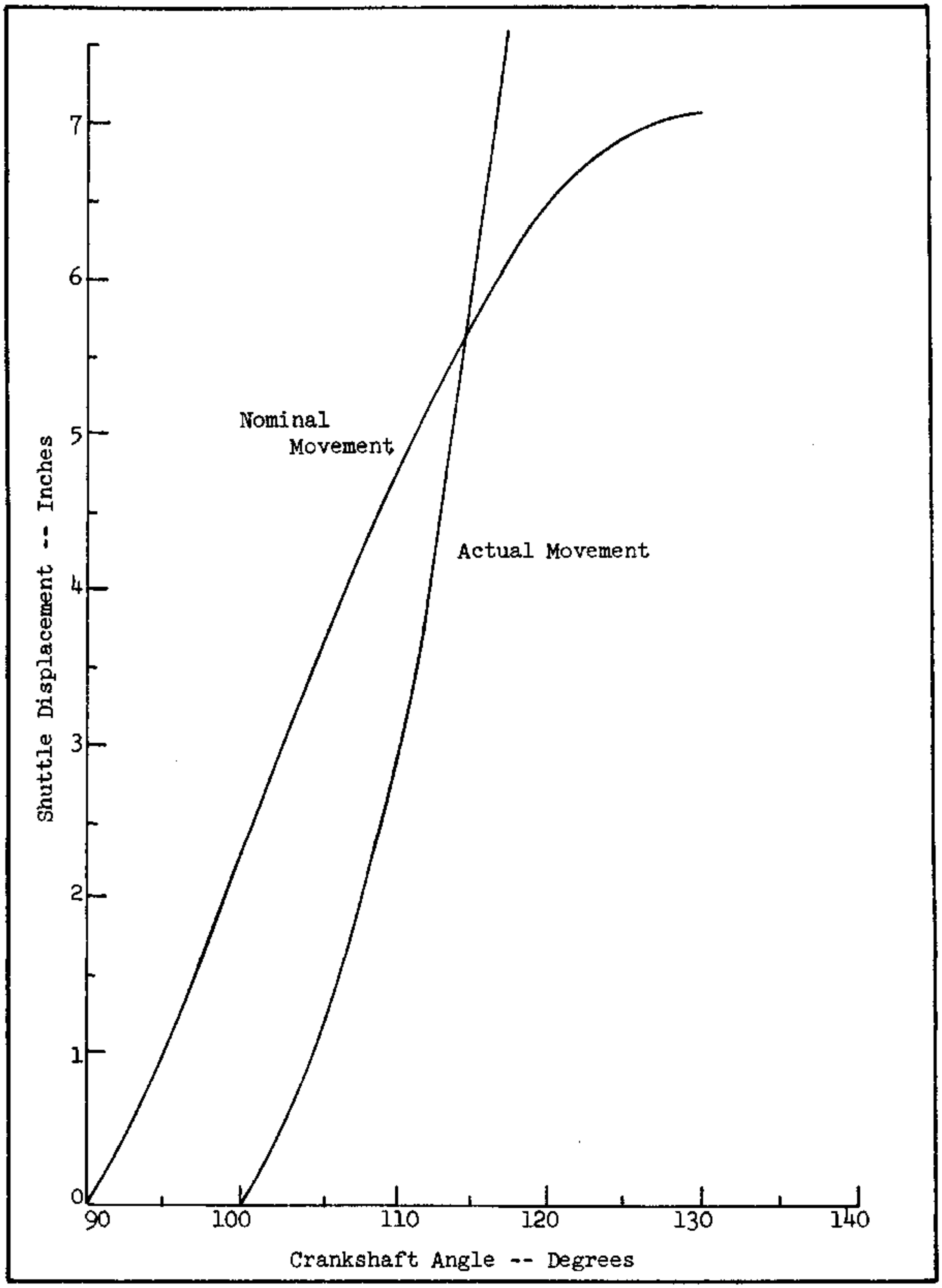


Figure 3. Nominal and Actual Movement from Left-Hand Box

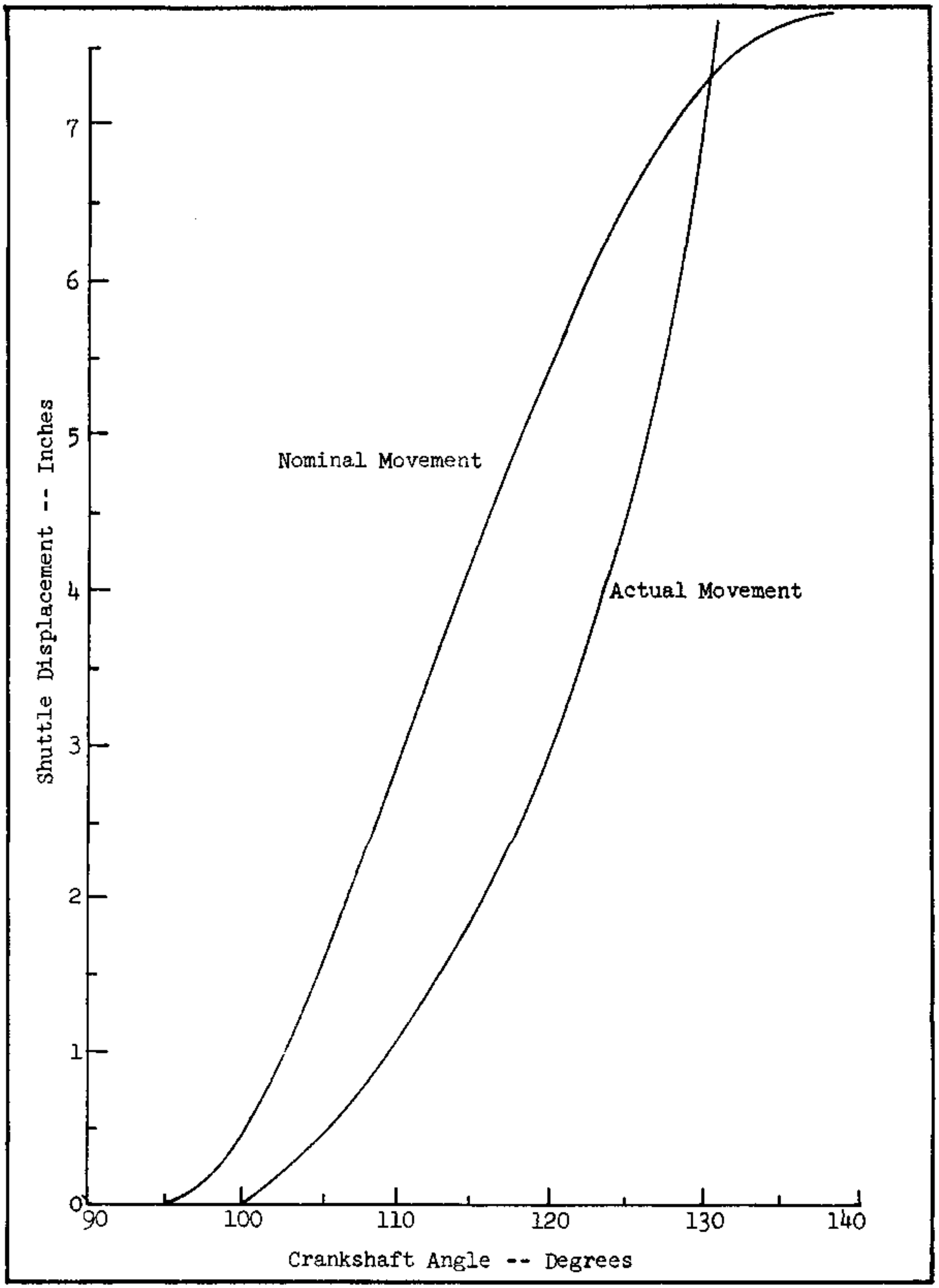


Figure 4. Nominal and Actual Movement from Right-Hand Box

Each of the curves (Figures 5 and 6) drawn from the data observed while the loom was running was subjected to graphical differentiation to determine the approximate maximum velocity the curve represented, a procedure often used with curves for which there is no mathematical formula. That technique made it possible to establish within reasonable limits how far the shuttle actually moved under the picker influence during the acceleration phase. From the values thus obtained the velocities at the end of the acceleration periods were calculated, using the relationship:

$S = V_0t \pm at^2/2$. With $V_0 = 0$ that expression becomes
$2S = at^2$. Solving for a:
$a = 2S/t^2$. Substituting $a = V/t$:
$V = 2S/t$. S (distance) was converted from inches to feet for all calculations.

Those peak velocities were used to draw straight-line curves (Figure 7) that reflect the drop in speed as the shuttle crossed the warp from left to right and from right to left. The final velocities for those curves were obtained from the expression:

$$V_a = (V_0 \pm V_f)/2.$$

The average velocities were gained by subtracting from the crankshaft reading at the end of 60 inches of movement (minus the position in inches at the end of the acceleration) the reading at the point of peak velocity, V_0. Those data are contained in Figure 8.

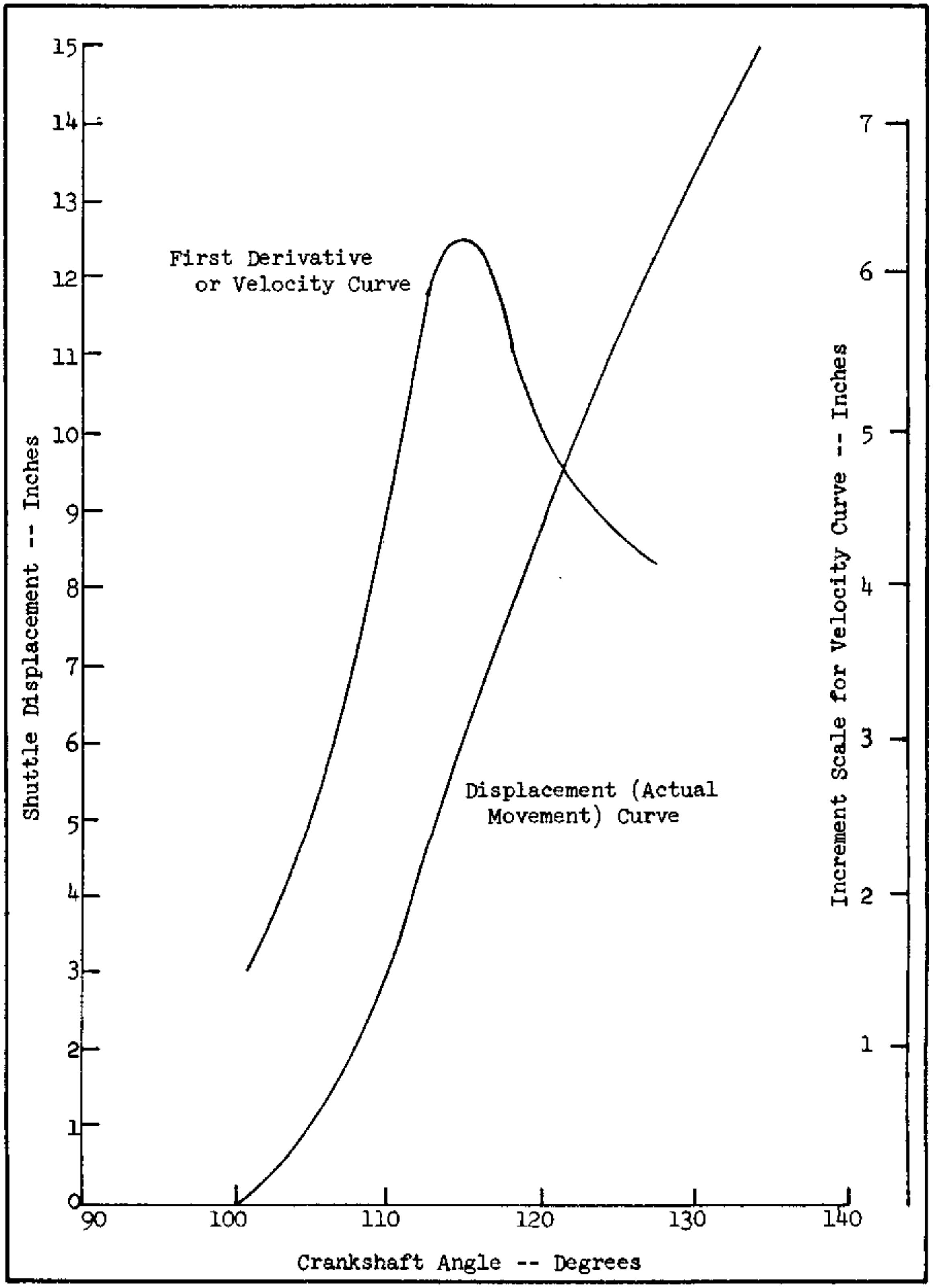


Figure 5. Graphical Derivative of Displacement Curve from L-H Box

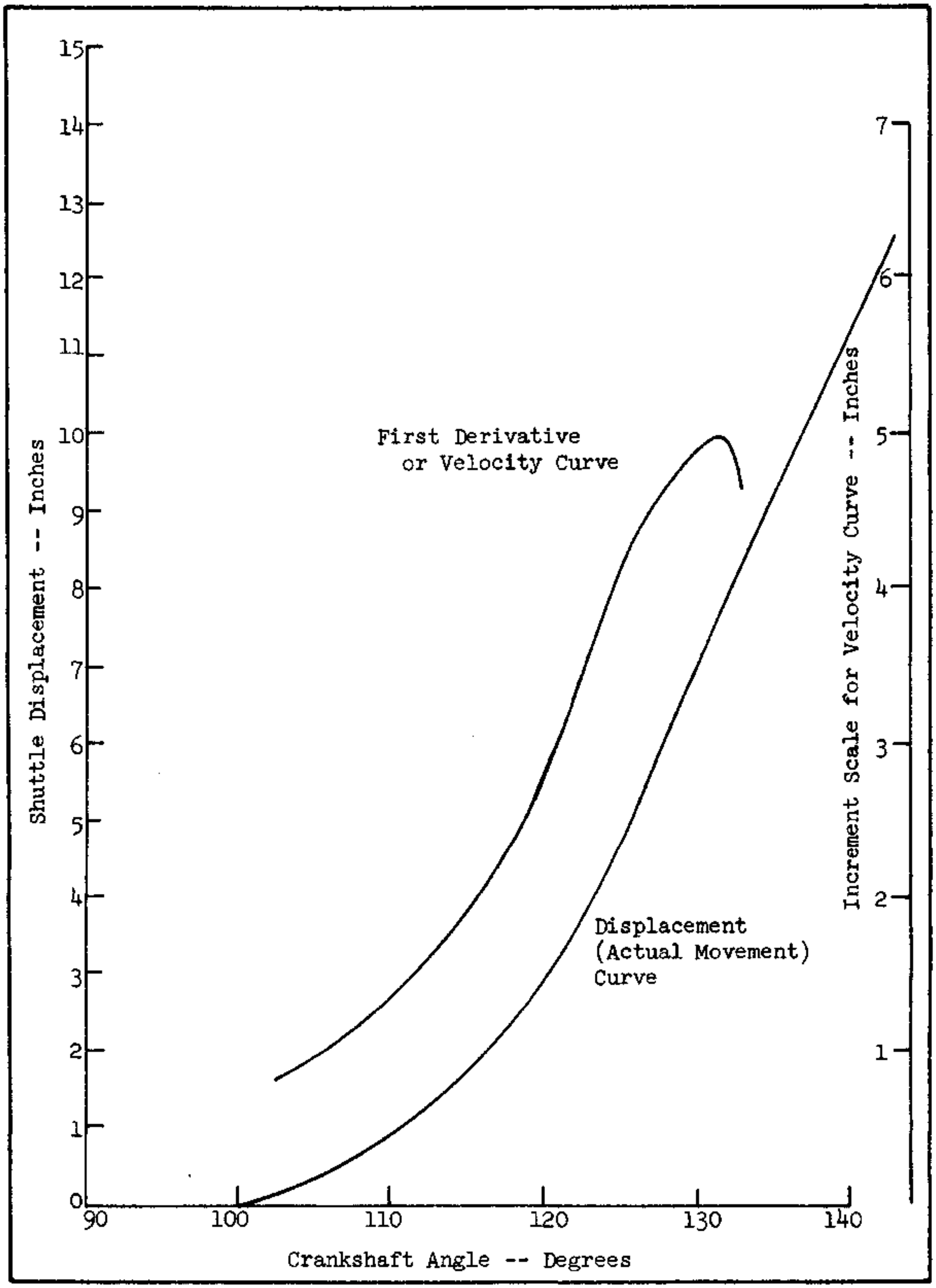
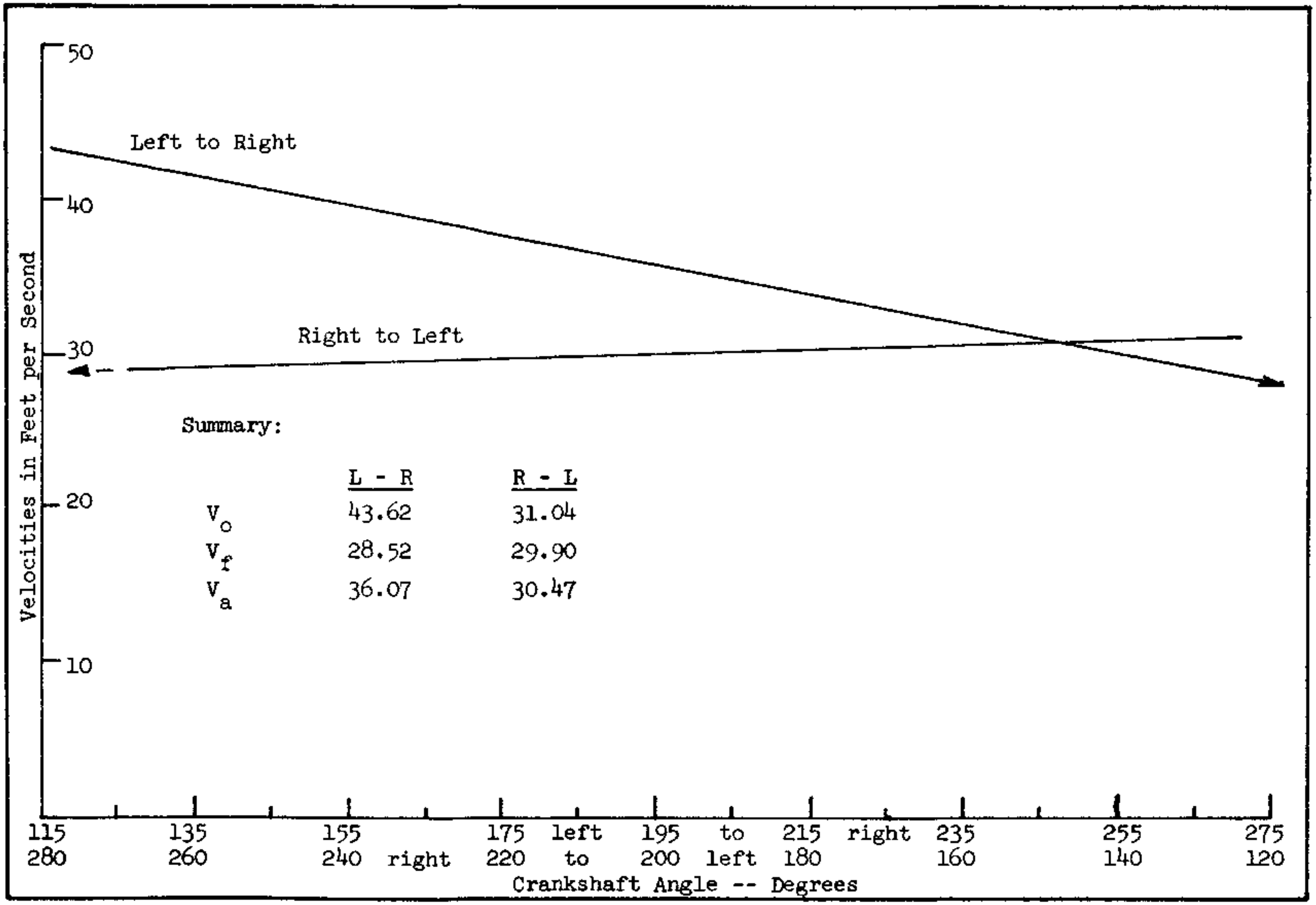


Figure 6. Graphical Derivative of Displacement Curve from R-H Box



Summary:

	L - R	R - L
V_o	43.62	31.04
V_f	28.52	29.90
V_a	36.07	30.47

Figure 7. Shuttle Velocity Decline Plotted as Straight Lines

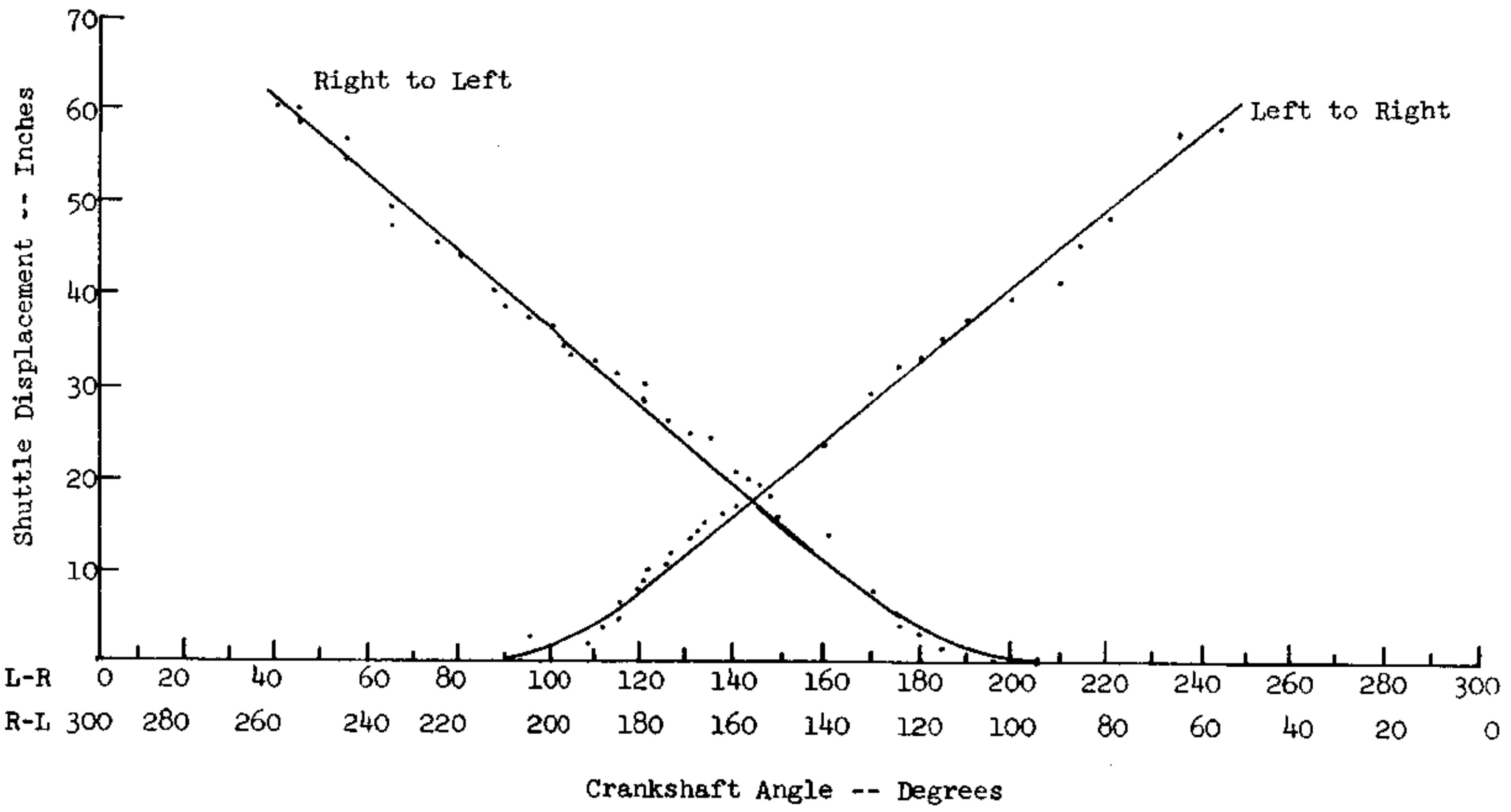


Figure 8. Displacement Curves

CHAPTER IV

RESULTS

The graphical differentiations show the shuttle reached a peak velocity at 6.3 inches in leaving the left-hand box; 5.0 inches in the right-hand box. From the actual movement curves in Figures 1 and 2, those values appear to occur at 116° and 124°, respectively. With a 90° starting point in the left-hand box, and a 95° point in the right-hand box, the corresponding net degrees are 26 and 29. Equated to time, those two net values are 0.02407 seconds and 0.02685 seconds, respectively. Thus, the accelerations and velocities from the two boxes are:

LEFT HAND:

$a = 1812$ ft/sec^2 at 6.3 inches and 116°

$V = 43.62$ ft/sec at 6.3 inches and 116° (V_0 for Figure 7)

$V_a = 36.07$ ft/sec from 6.3 inches to 60 inches

$V_f = 28.52$ ft/sec at the 60 inch point

RIGHT HAND:

$a = 1225$ ft/sec^2 at 5.0 inches and 124°

$V = 31.04$ ft/sec at 5.0 inches and 124° (V_0 for Figure 7)

$V_a = 30.47$ ft/sec

$V_f = 29.90$ ft/sec

The total flight times from the respective boxes, beginning at the 90° and 95° settings already mentioned, and continuing to the points on the graphs in Figure 5 where the shuttle met the 60 inch positions, amount to 160 degrees (0.14816 seconds) from the left and 163 degrees (0.15094 seconds) from the right. The average velocities corresponding to those times amount to 33.74 ft/sec and 30.36 ft/sec.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

There are pick-to-pick variations in shuttle velocities that refute certain classical theories about shuttle flight. The shuttle's position against the picker, the shear in the cam shaft, the stretch in the picking straps, the shear in the pick shaft and the distortion in the pick shaft and pick arm, and the flexing of the picker stick all possibly create a cocking effect that imparts nonuniform acceleration.

The part the shuttle's position against the picker plays at the beginning of the picking phase is well-known to loom mechanics and to management. But it is difficult to measure.

While the strobe lights can disclose that the picker spur is not in intimate contact with the picker, it cannot disclose how tightly it may be pressed against the picker. If there is any space between the two as the picker begins its movement, there is a subsequent loss of picking power that may or may not have visible effect on the subsequent pick.

The loom under study had a faulty picking motion on the left side that required timing it 5° early to get the shuttle into the right-hand box before the protector motion cut in to stop the loom. The curve plotted from the values read from that side of the loom shows a more distinct wandering pattern in distance against time than did the more properly functioning picking motion on the right side. Just how the picking motion from the right side was able to describe such a relatively smooth picking pattern is conjectural.

Furthermore, the acceleration from the left side, and the peak velocity, is greater than the more smoothly working motion on the right side. The velocity from the left side also fell off more quickly than did that from the right side for some reason(s) not disclosed by the study. There was no noticeable difference in warp interference between the two shuttle paths.

The system used for this study is not suited for the study of shuttle velocities per se. While the strobe lamps are most useful in observing such variables as shuttle attitude in flight, its angle of entry into the box, its bounce out of position as it is stopped at the end of its flight, its alignment with the reed during the crossing, and its contact with the warp yarns in entering and leaving the shed, they must be used at a distance from the loom that precludes accurate readings. Parallax is ever present and is quite real when trying to read either shuttle position against a mark on the lay or hand rail or pointer over handwheel graduations. The time elements are too small to allow such errors.

The data collected as in this study lend themselves poorly to plotting; just as poorly to mathematical formulation. And much of the problem springs from the nature of the loom operation. If the loom threw the shuttle in a predictable pattern from pick to pick, the parallax problem could be refined sufficiently to overcome serious error. As it proved, the researcher is forced to bend his data to fit the visual observations--the known quantities such as the point at which the shuttle leaves the picker influence and the point at which it contacts the binder swell. Acceleration cannot proceed beyond either point, but just where in the acceleration phase does picker influence cease? Only the graphical differential disclosed the distances that proved useful--both the 6.3-inch and the 5.0-inch increments were within the limits of observed data. Even so, the accelerations and the velocities found herein are debatable, for a second or a third plot of the actual movement curve will introduce entirely different results.

A suggested valuable use of the strobe lamps is akin to the principle used in timing automobile engines. Timing marks placed well within view on the loom hand rail or shuttle boxes could be used to check the shuttle's position as it approaches and leaves the shed and as it passes the center fork position in the middle of the lay. Instead of graduated handwheels, as most fly-shuttle looms are not equipped with them, the Draper pick timing gauge could be used to set the contactor that flashes the lamps on cycle. Any aberrations in shuttle and harness timing could quickly be found. If actual shuttle velocity is needed, resort to several known methods of photographing the shuttle along a known distance against a known time.

Recommendations

Further work in incremental shuttle velocities is of doubtful value to the industry at the moment. The fly-shuttle loom seems to have had its day and is being replaced by several types: rapiers, filling carriers, and water- and air-jets. Conceivably fabrics requiring two conventional selvages will one day demand a premium price.

Much work remains to be done on the new types. The very speeds with which the rapiers of the Draper Shuttleless Looms stuff a loop of yarn into the fabric create added filling breakage. The free end of the cut length of filling travels at twice the rapier speed, which in itself is usually faster than shuttle speeds.

The loose end of the rapier and jet types allow twist to run out of the filling and introduce side-to-side shading problems.

At the moment fly shuttle looms could be studied for the retarding effects the warp has on shuttle flight, whether the interference is brought on by poor pick timing, bad harness settings, or wear in either or both systems. The timing points, however, need not be related per se to shuttle velocities. Simple timing marks on the lay or hand rail, coupled with index marks on the top of the frog, would allow management to make routine checks of shuttle flight at critical points: (1) entering the shed; (2) passing the center fork; (3) leaving the shed; and (4) meeting the binder swell.

In the first category, the shuttle is usually timed to start moving only when the shed is fully opened. Nonetheless, if the cloth width is maximum for the loom under study, the shuttle will nudge the top and bottom sheds even as the lay moves toward back center where the shed is fully open and is wide enough to accept the shuttle.

Center forks are known to scrape a shuttle wall badly within a few hours and to leave fork marks in the cloth if the collision is great enough. The strobe lamp can be timed to pick up the shuttle just before it enters the fork area to give a visual inspection before trouble starts.

As the shuttle leaves the shed the lay is moving forward, bringing with it the shuttle toward the narrow part of the shed. There is some interference at that point, but it often is harmless. The shuttle slides by unless the shed closes too early. The strobe units and contactor can be used to ascertain if interference with the entering shuttle is more damaging than with the departing shuttle.

The fourth area involves the loom protector motion. To prevent trapping the shuttle within the shed and driving it forward sideways through the warp, the loom is fitted with a dagger or brake system that stops the mechanism within a few milliseconds if the shuttle is detected out of its box as the loom beats up. On the typical Draper loom the shuttle nudges the back binder, which is pivoted against a finger that swings the protector rod and lifts the dagger over the frog steel to prevent the sudden stops called "bang-offs." The dagger should begin swinging upward while it is still a safe distance away from the frog steel. That distance is variable but is in the region of one inch or one and one-fourth inches and is easily examined with the strobe and contactor. It is an excellent timing point, and if the shuttle shows an erratic flight the dagger will not lift at the same point each time. The dagger is perhaps the best barometer of faulty picking.

APPENDIX

Table 1. Degrees of Crankshaft Rotation Equated to Average Time in Seconds (1° = 0.000925925 seconds)

Degrees	Seconds	Degrees	Seconds
10	0.00926	190	0.17592
20	0.01852	200	0.18518
30	0.02778	210	0.19444
40	0.03704	220	0.20370
50	0.04630	230	0.21296
60	0.05556	240	0.22222
70	0.06481	250	0.23148
80	0.07407	260	0.27040
90	0.08333	270	0.25000
100	0.09259	280	0.25926
110	0.10185	290	0.26852
120	0.11111	300	0.27778
130	0.12037	310	0.28704
140	0.12963	320	0.29630
150	0.13889	330	0.30555
160	0.14815	340	0.31481
170	0.15741	350	0.32407
180	0.16667	360	0.33333

Table 2. Crankshaft Position vs Shuttle Position from Box

Crankshaft Reading (°)	Shuttle Position in Inches From Left-hand Box	Shuttle Position in Inches From Right-hand Box
90	0	0
95	-	0
100	-	0
105	1, 3	-
108	2	-
110	3, 4	1
111	4	-
115	5, 6, 7	2
117	7	-
119	8	-
120	8, 8, 9	3, 3, 4
121	10	-
125	10,11	5, 4
126	12	6
130	13,14,15	7, 8, 8
133	15	-
134	-	9
135	-	10
137	16	-
140	17	14,14
145	19	14
150	20,21	16
153	-	18
155	23	-
157	23	20
160	24,25,25	21
162	25	-

Table 2. Crankshaft Position vs Shuttle Position from Box (Concluded)

Crankshaft Reading (°)	Shuttle Position in Inches	
	From Left-hand Box	From Right-hand Box
165	-	24
170	29	23,25,25
175	33	26
180	33,33	28,30
185	35	31
190	35,37	32,32
195	37	33
197	-	34
200	39,41	36,36
205	-	37
210	41,42,45	38,39,40
212	-	40
215	45	42
217	45	-
220	48,49	44,44,45
225	51,52,53	45
230	53,55,57	48
235	57	47,49
240	53,57	53
245	58,59,60	54,56
250	60,60	57
255	61	58
256	-	60,60,60
257	63,65	-
260	63,65	-
265	-	62
270	65,65	64
275	66	65
280	66	65,66
285	66	65
290	-	66

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