Of Wooden Arrow Performance, Design and Build

Part 1 is a brief practical examination of how wooden arrow performance changes with alterations in mass, fulcrum, surface area and profile, and Part 2 an "everyman's" approach to how arrows may be designed and made.

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Foreword

by Jeremy Spencer 2023
Master Bowyer
Former Warden of The Craft Guild of Traditional Bowyers and Fletchers

I first met Joff at a Warbow Wales shoot a number of years ago, which is no small matter as he travels far and wide from his home in the East of Britain to participate in his passion, longbow archery. It is a highly social sport, and interesting conversations between shots during a roving marks shoot are as important a part of it as the shooting. During these conversations much information is swapped and pondered and I was struck by Joff's unassuming and cerebral manner which demonstrated an analytical mind free of archery dogma. It was during one of these conversations that he discussed his ideas with me and I know this paper has been a long time in the planning and methodical preparation.

Joff is ideally placed to write this paper, with a skillset that combines all of the needed facets; personal, practical and theoretical. It is a testament to how well thought of he is by how many people were prepared to be a part of this work. They won't be disappointed, it is crammed full of well-researched data. The paper provides an authoritative work that combines innovative and accurate information in a highly readable and entertaining way; not always the case with academic works which can be a tad dry in their delivery. It helps to tease out some the medieval military arrow's martial design features and needs of mass production in relationship to pure performance untethered by war. I find this the most fascinating aspect. The author clearly understands the practicalities of military equipment in a dynamic of performance, reliability and cost to benefit. These are factors unchanged for hundreds of years. He has been able to demonstrate that some of the long-held beliefs about an arrow's flight characteristics are unfounded through practical experimentation and analysis.

There is also a clear how-to guide for archers to make their own arrows despite Joff being a commercial fletcher himself. This is, however, unsurprising as he is clearly in the camp of those wishing to share information rather than to control it. Indeed, there's so much information that the paper warrants re-reading because of the density of the data. It's also a refreshingly honest work, typically for Joff, without hint of grandiosity. Indeed, he is also always quick to credit the work of others, not least of all, Stephen Green who is missed by all who knew him. This paper is a valuable addition to the sum of knowledge we have about its subject. I am sure it will serve many in their own research for a considerable time to come.

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Acknowledgements

Pip Bickerstaffe started me on this road, and has provided several very useful jigs used in arrow manufacture. Sticky Green provided an excellent mentor – over a long period and not infrequent glasses of good ale his constant refrain was “prove it!”, perhaps the key stimulus. The folk in the rogue’s gallery very kindly provided their time and effort to take part in some, on the face of it, rather odd exercises. Abigail Parkes was the first to consider the earlier work purely analytically then advance it considerably in the area of exit velocities. She also provided a veneer of academic discipline to what would otherwise be little more than a pursuit of gentlemen of a certain age. I’m also indebted to Jeremy Spencer, Joe Gibbs and Alaistair Pinfold of the Cerne Abbas Archers for their input into the demands of particularly heavy bows, and Ian Sturgess in the same light. Julian Coleman both provided very useful input on existing works in this field and quite the most elegant fletching jig, and John Spencer independently tested out the contentions with light bows in a howling Donegal gale. Jacek Kaminski also patiently explained the finer points and implications of using a thumb ring. Lee Ankers very kindly gave up a few hours of his time to both demonstrate winding fletches properly and showed me several invaluable short-cuts in arrow manufacture. There are many more whose input has been invaluable and has helped shape this investigative foray, not least those who’ve shot my arrows and come back for more! If I haven’t mentioned you by name it is because this is long enough as it is. Thank you. As ever, I claim all rights to errors, omissions and misunderstandings.

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Part I

Performance

Rogues' Gallery – The Participants

Gary Williamson
Archer & Captain of the Mercian Bowmen

Phil Kearey
Archer & Photographer

Rob Marshall
Archer

Nick Keogh
Archer

Phil Rees
Volunteer & Observant Gentleman

Stephen Green
Instrumentation & Analysis

Joff Williams
Principal Author & Fletcher

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What Happens to an Arrow in Flight? – Performance Measurement – Version 0.5

"Of course I shot him in the back. It's only a pity he was awake."
Arnold J Rimmer.

Contents

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Introduction

The contention is that there are 5 essential characteristics which govern how a set of arrows will behave. These are mass, spine, surface area (or drag), profile (i.e. usually parallel, bobtailed or barrelled steles) and balance point. They are adjusted according to the draw weight of the bow and what the archer intends to use the arrows for; the basic disciplines being field/short range target (say up to 30 or 40 yards), medium range targets (to perhaps 80 or 90 yards), long range target (including clout and roving clout), flight and popinjay. This short foray into measured results seeks to examine most of the characteristics less, at this time, spine. The opportunity was also taken to take a brief look at angles of strike compared with those of launch and exit velocities from various bow weights (with matched arrows).

It should be noted that the sample sets are statistically small and, whilst some rudimentary analysis has been applied, it should not govern any conclusions drawn but simply provide a pointer. Additionally only wooden arrows shot from wooden long and flat bows are under consideration.

The Hypotheses

The hypotheses put forward are as follows:

Table 1.

Hypothesis 1 – Drag	For a given bow, with all other characteristics held near equal, as the surface area of an arrow increases the range decreases.
Hypothesis 2 – Fulcrum	For a given bow, with all other characteristics held near equal, as the fulcrum of an arrow moves further towards the pile so the range decreases.
Hypothesis 3 – Profile	For a given bow, with all other characteristics held near equal, as the profile of the arrow is altered to a presumed better aerodynamic shape (i.e. parallel to bobtail then barrel) so the range increases (the Coandă effect).
Hypothesis 4 – Mass	For a given bow, with all other characteristics held near equal, as the weight of an arrow increases so the range decreases.
Hypothesis 5 – Angle of Strike	The arrow will follow a parabolic path in flight, meaning that angle of launch and angle of strike are equal[1].
Hypothesis 6a – Exit Velocity	As bow draw weight increases release velocity decreases with the inertia in the bow limbs and the heavier arrow.
Hypothesis 6b – Exit Velocity	As bow draw weight increases force and energy increases with increased arrow weight.

Experimental Error

The idea behind each experiment is to reduce the influence of factors which are not under examination as far as possible; hence using the same bow throughout most trials for example. Equally the archers kindly volunteering their time and effort are all capable of shooting bows at 100lb or more in draw weight; the low bow weight chosen (50lb @ 30”) for the majority of

[1] Please note that fletches sold as “parabolic” are more like a cord cut through an ellipse in shape; the hogsback is closer to parabolic.

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experiments meant that it was well within their capacity allowing, hopefully, for sustained consistency in the loose throughout the day. It is impossible to eliminate variations other than those under the microscope however so the approach taken is, whilst minimising other variables through careful arrow build, the characteristic in question is exaggerated to some extent to ensure that its influence can be seen above the noise of all the other factors. For example, Figure 1 below shows 3.25mm solder driven into steles in order to force the fulcrum. This is not that simple; for example the drag of a popinjay arrow will be vastly different to a flight arrow but the dissimilarities mean the comparison is not meaningful. In order to obtain sensible results the measurements taken are therefore not far above experimental "noise".

Similarly variations in the absolute range shot by each archer have not been used; instead differences from the mean strike points taken. This was to minimise the inevitable effect of each archer shooting with the, marginally different, technique each has developed through experience.

Figure 1. Modified arrows (fulcrum trial).

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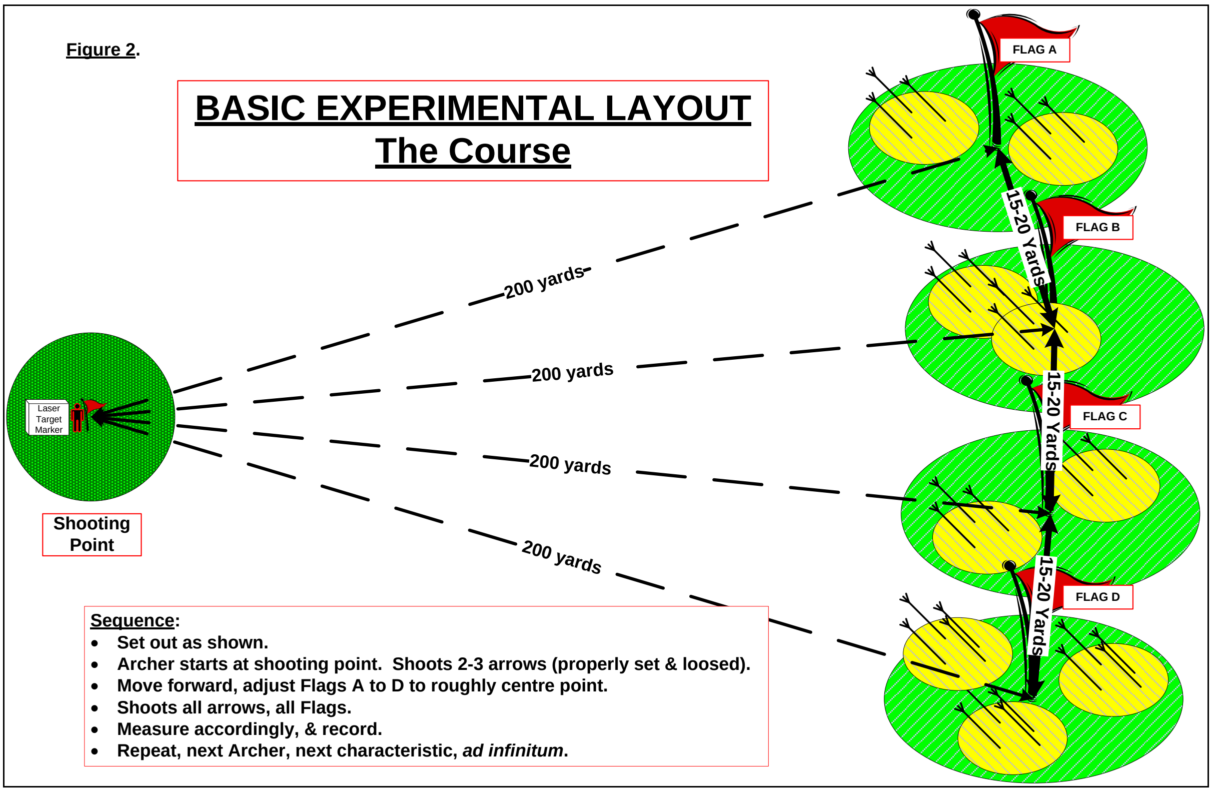
Basic Layout & Measurements

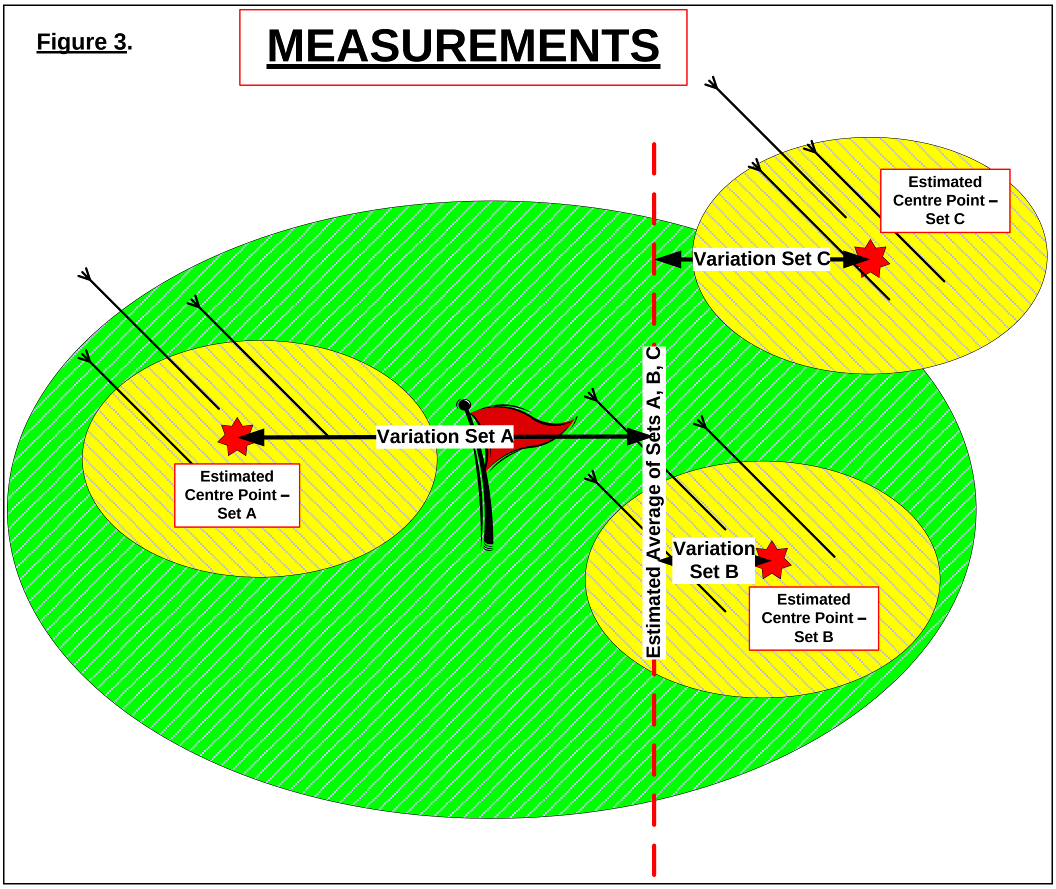
Figure 2.



Sequence:

- Set out as shown.
- Archer starts at shooting point. Shoots 2-3 arrows (properly set & loosed).
- Move forward, adjust Flags A to D to roughly centre point.
- Shoots all arrows, all Flags.
- Measure accordingly, & record.
- Repeat, next Archer, next characteristic, *ad infinitum*.

Figure 3.



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The exceptions to this methodology are with strike angle and exit velocity measurements. These are outlined at Annexes B and C. Examinations of profile, mass and drag were also repeated at Fort Purbrook using similar techniques to that for measuring exit velocity but those results have not been recorded herein, as time precluded sufficient shots to be of less value that the earlier work at Lount. In this instance, rather than measuring the differences in extreme range, strike height at a much shorter range was measured.

The Arrows

Sets of arrows were specifically built to examine individual effects. Their specifications are recorded within the Annexes; some of the survivors are in the group photograph at Figure 4. Generally the arrow quality was held to be high enough although some slap occurred with one archer, which transpired to be from a tendency to overdraw (evidenced by marking on the bow limb).

Figure 4. The remaining arrows.

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Experimental Conduct & Results

Results are summarised at Annexes A, B and C less strike angle and exit velocity, which do not contribute to the main thrust of this paper, which seeks to examine arrow characteristics; these 2 areas are closer to the interface between bow and arrow.

The first 2 hypotheses (concerning drag and fulcrum) were examined by experiment conducted at Lount, just outside Ashby-de-la-Zouch on the 7th August 2021. For location see satellite take-off in Figure 5, together with co-ordinates (Grid, Latitude/Longitude, What 3 Words). Participants were Messers Phillip Keary, Robert Marshall and Nicholas FW Keogh (the Archers), Stephen Green collecting data and looking at preliminary analysis, and Joff Williams with overall responsibility for the idea, conduct and detailed analysis of results. It is worth noting that drawing together enough willing and able archers and support staff along with the crude instrumentation used is not a simple task.

The same ground was used on the 10th October 2021; the participants this time being Phillip Keary, Robert Marshall, Gary Williamson and Phillip Rees (the Archers) with Stephen Green and Joff Williams in attendance as before. On this date the fulcrum element was repeated using a modified set of arrows as noted, and profile and mass examined. Additionally strike angle was explored.

Figure 5.

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Conditions were clear on both days with a wind veering South to South-South West averaging 15mph gusting 20mph (noting that the field indicated is shielded by rising ground to the South and West, and that arrows shot at about 45^0 rise above this protection at their apogee). There was no precipitation. There is a slight rise in ground elevation from the shooting point to directional flags of around 1%.

The idea behind the conduct of the experiments is as illustrated in Figures 2 and 3, using the instrumentation detailed in Appendix 1. Each set of arrows within each experiment was built to match with the characteristic under examination being varied within the set. Three arrows (plus a spare) were provided in each sub-set. Each archer was asked to shoot all of these 3 times and the centre-point of strike of each group of 3 was taken; the measurement is of variations in the centre of strike rather than absolute distance to attempt to minimise the influence of individual archer behaviour as noted. The exceptions are that differences in angle of launch and strike used a 45lb flatbow and separate set of a dozen clout arrows (to allow some concurrency).

All results are available in spreadsheet format on request. Where it is sensible to do so results have been converted to Standard Integrals although, as this is a comparative rather than absolute analysis, units used are not that important.

Figure 6. Rob Marshall and Phil Rees in action on the shooting line.

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Figure 7. Garry Williamson, Phil Rees and Joff Williams measuring up.

Figure 8. The intellectual powerhouse; Stephen Green, Phil Rees and Joff Williams. Oh well.

Results and Conclusions. Detailed results are at Annexes A, B & C.

Table 2.

Hypothesis	The Argument	Conclusion
Hypothesis 1	As the surface area of an arrow increases the range decreases.	True with a moderate degree of confidence.
Hypothesis 2	As the fulcrum of an arrow moves further towards the pile so the range decreases.	Not true. There appears to be an optimum balance point. Placing the fulcrum either side of this reduces range.
Hypothesis 3	As the profile of the arrow is altered to a better aerodynamic shape (i.e. parallel to bobtail then barrel) so the range increases.	True with a high degree of confidence.

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Hypothesis	The Argument	Conclusion
Hypothesis 4	As the weight of an arrow increases so the range decreases.	True with a high degree of confidence.
Hypothesis 5	The arrow will follow a parabolic path in flight.	Not true. The arrow follows a path lying between an ellipse and a parabola.
Hypothesis 6a	As bow draw weight increases release velocity decreases with the inertia in the bow limbs and the heavier arrow.	Not true. Release velocities, for the same or similar ratios of arrow weight to draw weight, remain the same.
Hypothesis 6b	As bow draw weight increases force and energy increases with increased arrow weight.	True.

Observations.

- This is a coarse analysis of a limited set of results. Ideally, to achieve statistical significance, more archers and more arrows would have been ideal but practical considerations precluded this, not least daylight available and the need to gather results. As a consequence it is reiterated that conclusions derived are indicative rather than absolute.
- R-Squared (R^2 or the coefficient of determination) is a statistical measure that determines how well the data fits the regression model (the goodness of fit). R^2 values of 0.75, 0.50, or 0.25 can, as a rough rule of thumb, be respectively described as substantial, moderate, or weak. (Investopedia). If you're really that interested. These are displayed on most of the graphs.
- Arrow breakages were catered for by having a spare for most sets. Nonetheless on the first day 2 breakages occurred (both relating to drag measurements); on the second two more were broken which Murphy's law dictated came from the same set of 4 (relating to fulcrum). In both cases centre points of strike were therefore taken between the 2 survivors for the remaining ends.
- The anthropomorphic limits of the archers proved to be of interest. One naturally drew to 34" being of some height and strength; at the other end of the scale an equally strong archer had a natural draw length of some 29". Given that these good gentlemen were asked to shoot several dozen arrows apiece and retrieve them over the course of a day there was an expected tendency to revert to natural draw lengths limited by arrow length. To compensate for this, as noted, the average strike point for each archer across all ends shot within each experiment was estimated and deviations from the average measured as noted.
- A crack developed in the bow about 3/4ths of the way through the second day; again not surprising given that the poor old girl was over 20 years old (with one facelift). In inimical archers' fashion gaffer tape and cable ties got her through the remainder of the day with no measurable loss of draw strength. In retrospect the same bow was not necessary; should all archers have used their own bows with the same draw weight and length the method of measurement would still allow for valid comparisons.

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Further Work

The only area where different bow weights have been used is in investigating exit velocities. The preference of archers shooting heavy bows is for relatively large fletchings; probably to replicate medieval and renaissance practice. A study of the effect of varying drag at the heavy end would be of interest. Coupled with this investigation of air flows over fletchings of different shapes would both provide some indicator of the ideal medieval fletch and inform design for different modern purposes.

Fulcrum is also of interest, in that each set of arrows appears to have a particular "sweet spot". It is speculated that this may well be related to spine; Hugh Soar notes South American Indians finding the individual ideal resonance of each individual arrow through gradually cutting down the length resulting in differing lengths for the same archer (pretty much anathema to most club archers). This would certainly provide an extensive piece of work to determine the relationship.

Insofar as mass is concerned the variation chosen has been within a range to reduce risk to the bow. Logically, from these results, flight arrows should therefore be made as light as possible yet this is not the sole factor determining high performance (setting aside the quality of the bow itself). It may be of value using a bow which will take a fair amount of punishment and investigating what happens as arrows get steadily lighter.

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Annex A – Results

Surface Area (or Drag)

Hypothesis 1 – For a given bow, with all other characteristics held near equal, as the surface area of an arrow increases the range decreases.

Chart 1.

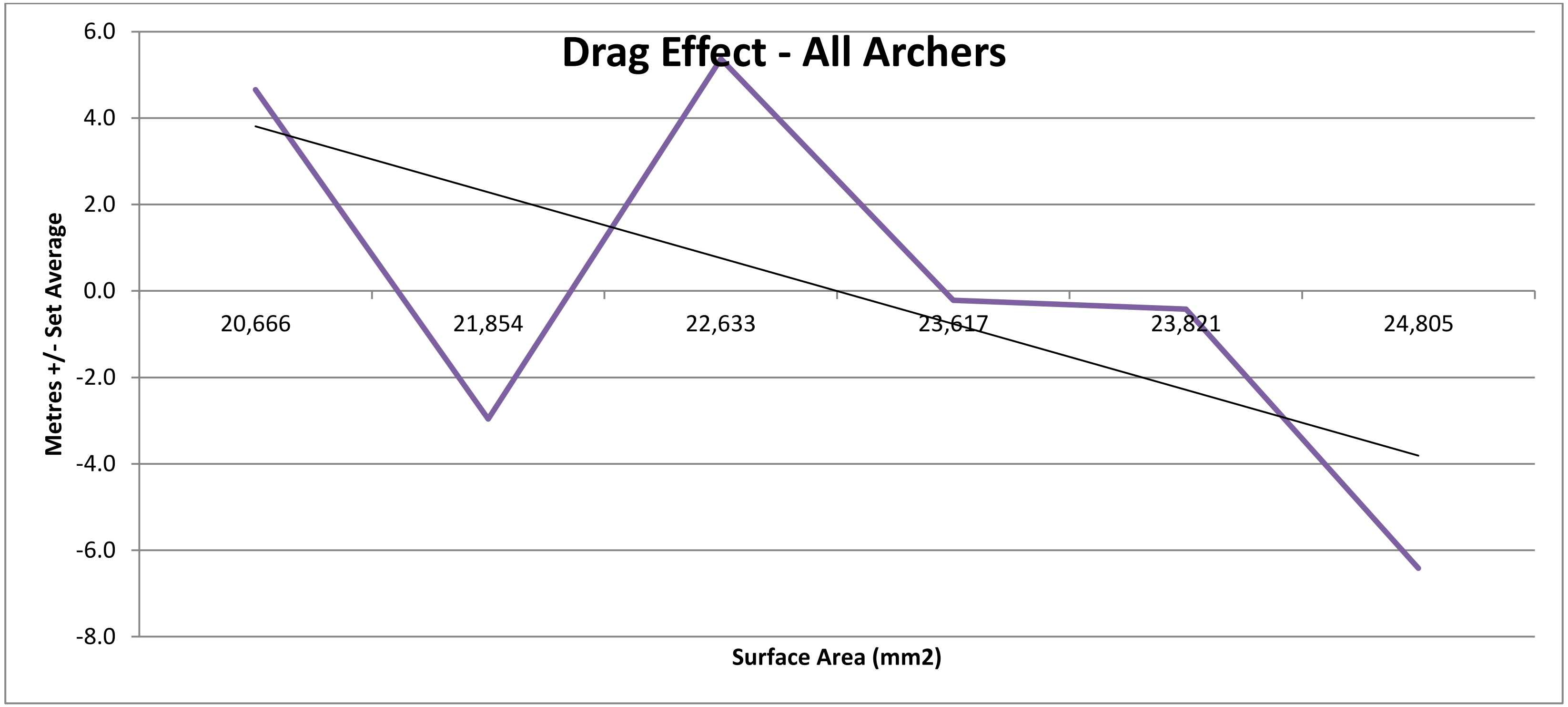

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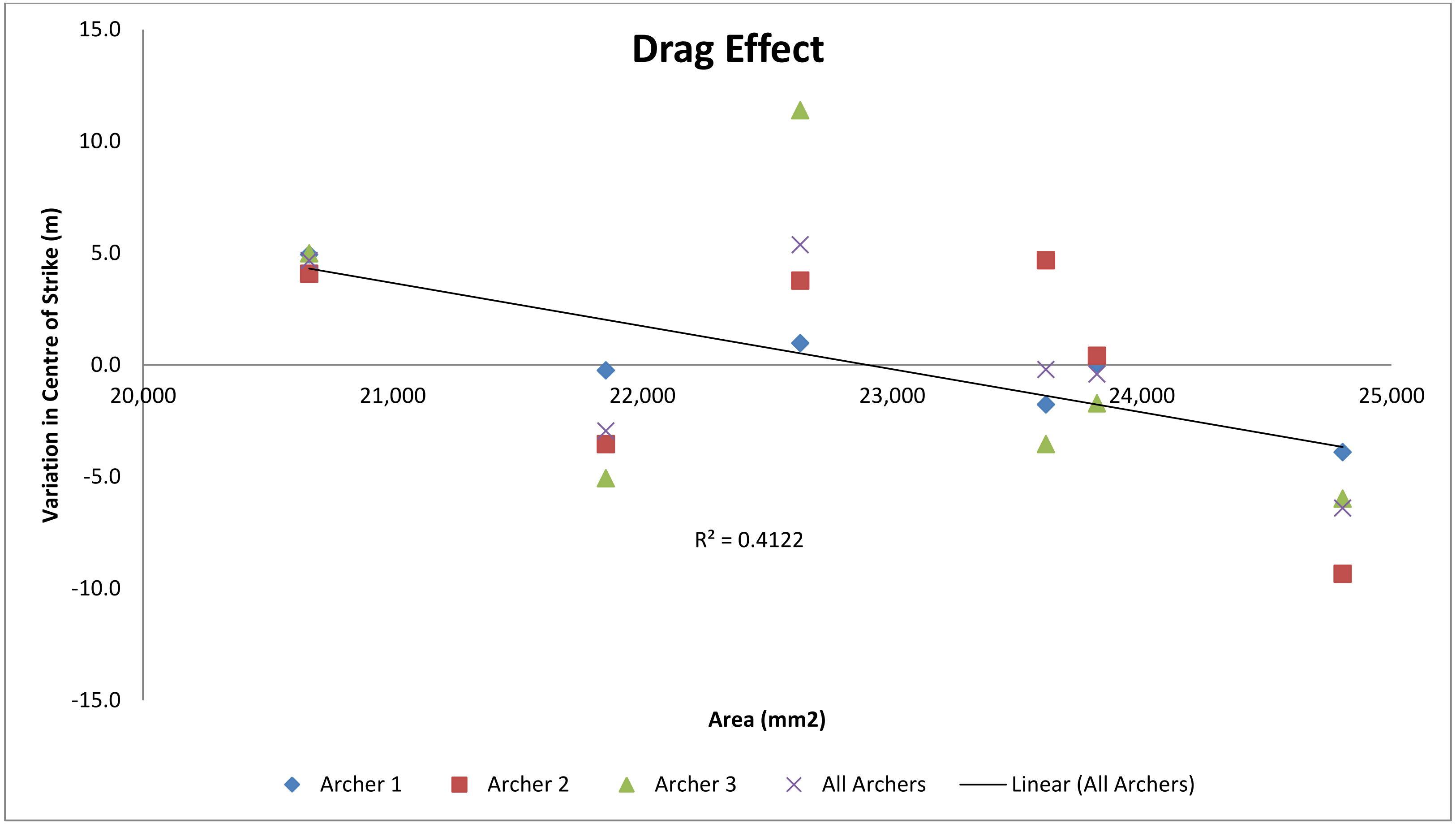
Chart 2.



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The Arrows

Common Parameters:

- Draw Length – 30”.
- Spine ≥50lb less 23/64”; 65lb.
- Release angle - ~45^0.
- Weight – 510gn +/- 1½%.
- Balance Point – 10 & 5/8” behind the pile, +/- 1/16” (35%).
- Fletches Gateway L/W parabolic.
- Piles 125gn brass screw bullet, tapered & shouldered.

Table 4.

Set	∅	Crown Stain	Cock	Hen	Nock	(Weight)	Surface Area[2]	
							In^2	mm^2
165	23/64”	Blue	3” Patriot (UK)	3” Russet	White	520gn +/- ½%	36.61	23,617
166		Yellow/Red Crest	4” Patriot (UK)	4” Light Blue			38.45	24,805
167	11/32”	Red	3” Purple	3” White	Green	510gn +/- 1½%	32.61	22,633
168		Blue/Yellow Crest	4” Brown	4” White			36.92	23,821
169	5/16”	Green; Yellow/Red Crest	3” Green	3” Lime Green	Orange	510gn +/- 1%	32.00	20,666
170		Green; Light Brown/Red Crest	4” Yellow/Brown	4” White			33.87	21,854

[2] Accuracy of measurement a trifle on the ambitious side.

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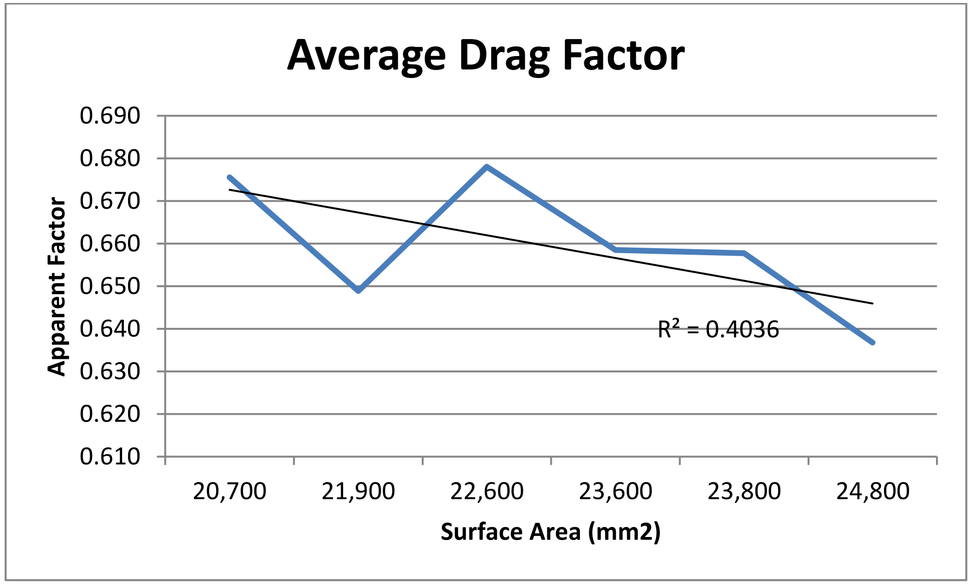
Observations

There is a distinct trend for range to drop with increased surface area, as expected, although the R^2 value at just over 0.4 only allows for a moderate degree of confidence. This suggests that the differential in surface area is only just above experimental noise, particularly archer consistency in the loose. This is reasonable as this was the first trial conducted and the high quality of the archers involved, all of whom shoot instinctively, led to a natural tendency to attempt to hit the flag rather than focus on the release.

One other aspect may be drawn from the data, as illustrated in Chart 3. If the "Galilean" range is calculated and compared with actual ranges achieved some indication of the effects of atmosphere may be deduced. It is suggested that these results should be viewed with caution as they could only be applied to a particular bow and a particular set of conditions.

Chart 3.



Conclusions

The hypothesis, as the surface area of an arrow increases the range decreases, is not disproven.

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Fulcrum

Hypothesis 2 – For a given bow, with all other characteristics held near equal, as the fulcrum of an arrow moves further towards the pile so the range decreases.

Chart 4.

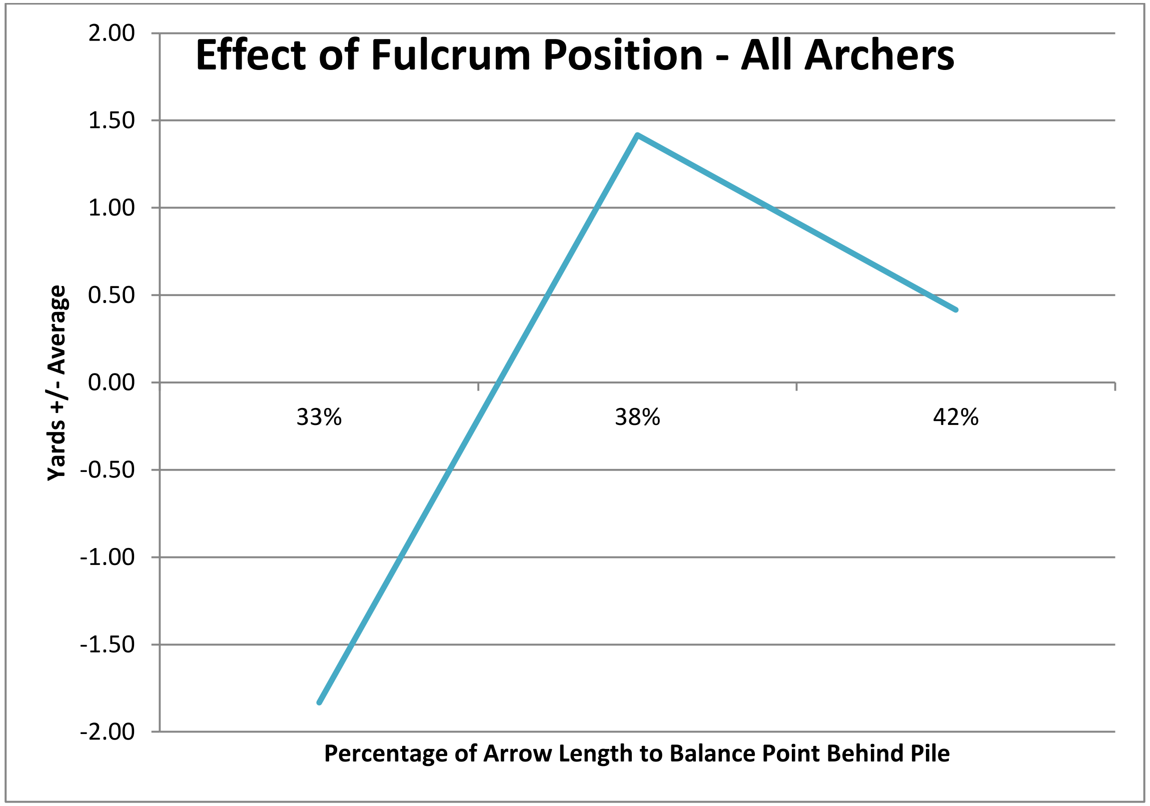

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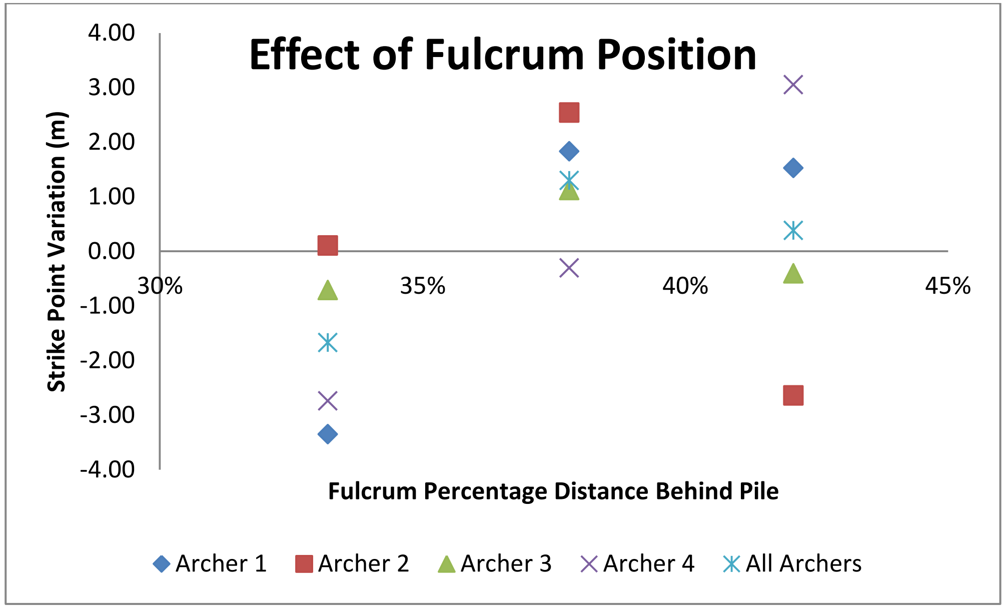
Chart 5.



The Arrows

Common Parameters:

- Draw Length – 30”.
- Spine ≥50lb.
- Release angle - ~45^{0}.
- Weight – 575gn +/- 2%.
- ∅ 11/32” pine bobtailed to 5/16”.
- Fletches Gateway 4” L/W parabolic, bound.

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Table 5.

Set	Balance Point	Balance Point (% of Arrow Length)	Arrow Length	Pile Length	Crown Stain	Cock	Hen	Nock	Pile
213	10½" behind the pile	33%	31 & 5/8"	1 & 3/8"	Red	Red	Yellow	Red	125gn brass screw bullet
214	12" behind the pile	38%	31¾"	1½"	Black	Black	Yellow	Black	100gn brass screw bullet
215	13¼" behind the pile	42%	31½"	1¼"	Blue	Blue	Yellow	Blue	80gn brass screw bullet

Observations

These were the arrows with 3.25mm solder driven through their steles to force a wider variation in fulcrum position. It is hardly surprising that 2 broke.

The indication is that there is an optimum point of balance; as the fulcrum moves further away from this, either forward or aft, so the range decreases. From physical observations carried out at a later date (Stephen Green and Joff Williams on 28th December 2021, at the same site) those arrows demonstrating shorter ranges exhibit a clear pitching behaviour, in some instances as cork screwing where the archer's release was less than perfect. This latter effect is a subjective observation only as we have yet to think up any means of providing a quantitative measure. It is tentatively suggested that where the balance point is forward the tendency of the arrow to dip is being corrected as the surface area of the fletch presented to the airflow increases; conversely where the balance point is aft the tendency to plane is being similarly corrected.

Conclusions

The Hypothesis – that as the fulcrum of an arrow moves further towards the pile so the range decreases may be held to be true ***but*** range also decreases as the fulcrum moves towards the fistmele. There is a clear optimum balance point.

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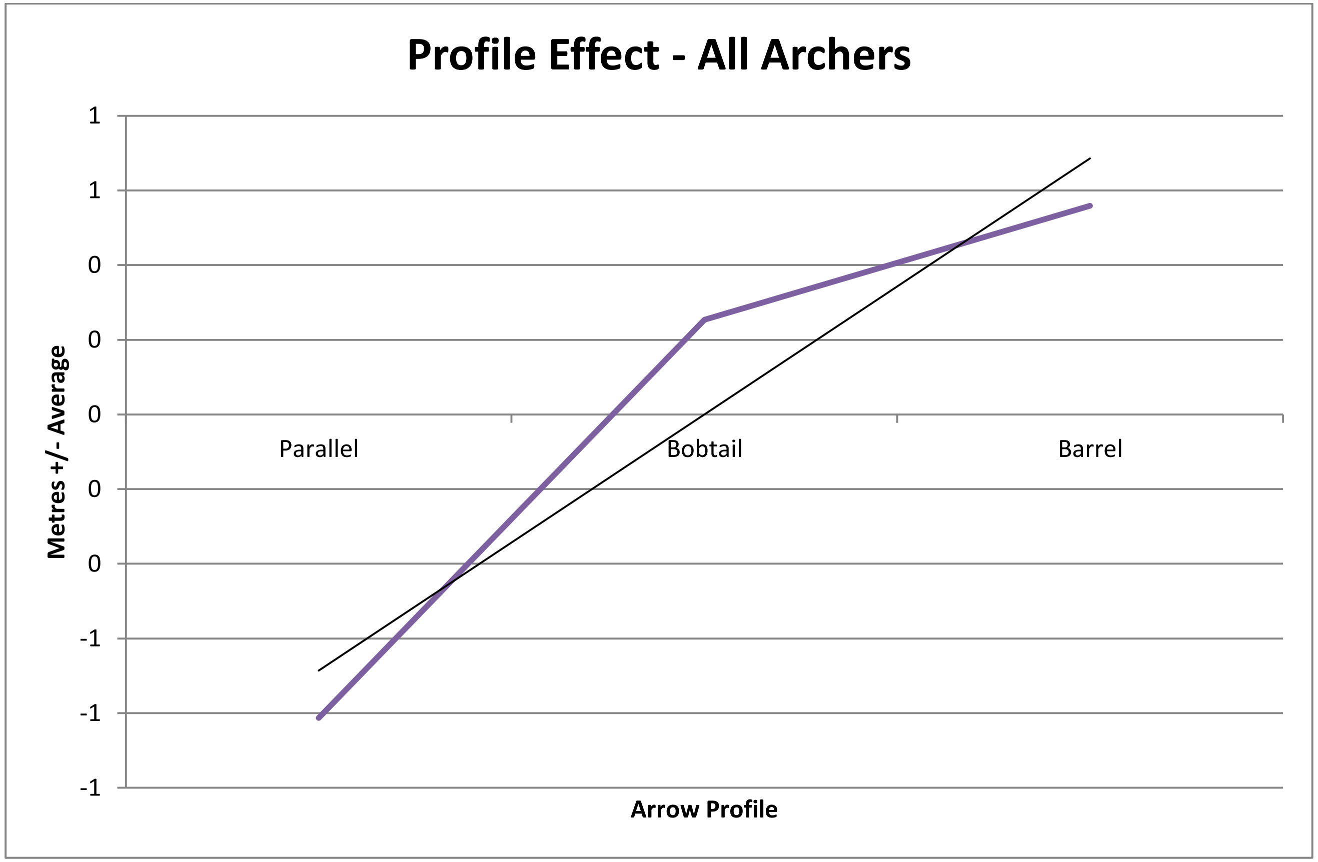
Profile

Hypothesis 3 – For a given bow, with all other characteristics held near equal, as the profile of the arrow is altered to a presumed better aerodynamic shape (i.e. parallel to bobtail then barrel) so the range increases (the Coandă effect[3]).

Chart 6.



[3] https://en.wikipedia.org/wiki/Coand%C4%83_effect

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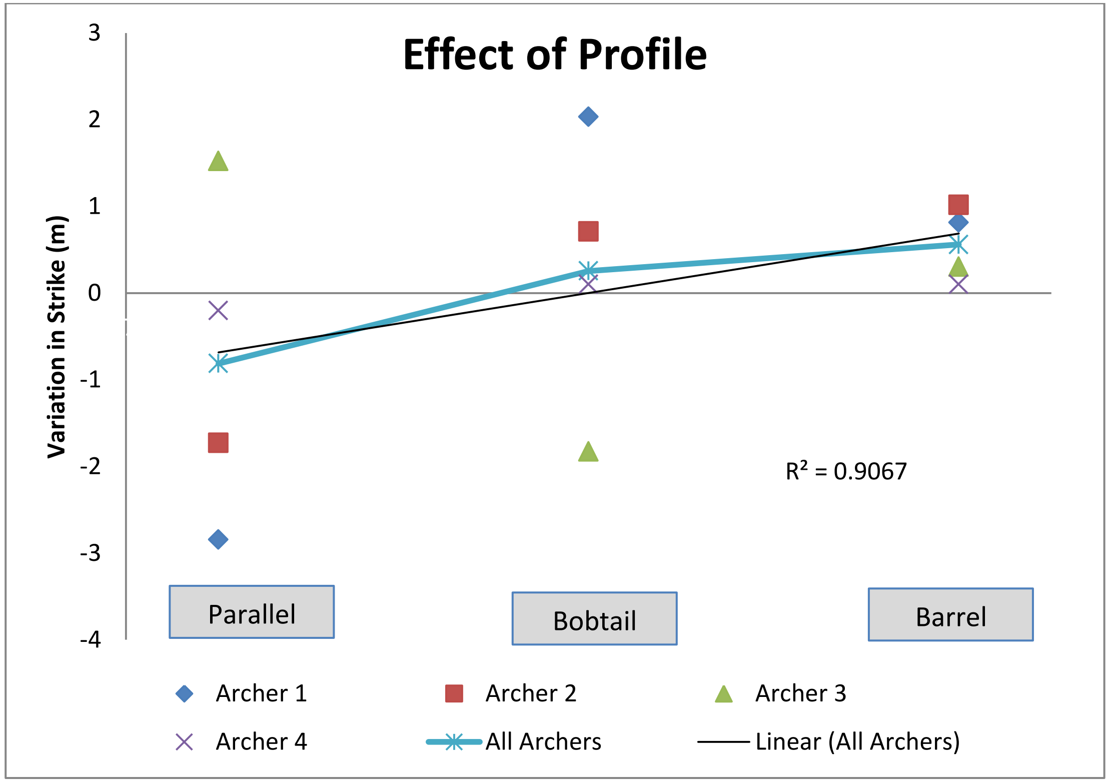
Chart 7.



The Arrows

Common Parameters:

- Draw length – 30”.
- Spine ≥ 65lb.

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- Release angle - ~45^0.
- ∅ – 23/64” cedar.
- Pile – 125gn brass screw.
- Point of balance – 10 & 5/8” behind the pile.
- Fletch – 4” L/W parabolic bound.

Table 6.

Set	Profile	Crown Stain	Cock	Hen	Nock	Weight
166	Parallel	Blue	Patriot (UK/FR)	Light blue	White	520gn +/- ½%
286	Bobtail to 5/16”	Green	Green	Light blue	Green	535gn +/- ½%
287	Barrel to 5/16” & 5/16”	Red	Red	Light blue	Orange	525gn +/- ∅%

Observations

There is a clear tendency for range to increase as stele profiling is refined. Perhaps unexpectedly, at least to the author, barrelling appears to demonstrate slight advantages over bobtailing. The high R^2 value, at 0.9, reinforces confidence in the result.

Conclusions

The hypothesis, as the profile of the arrow is altered to a better aerodynamic shape (i.e. parallel to bobtail to barrel) so the range increases is proven.

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Mass

Hypothesis 4 – For a given bow, with all other characteristics held near equal, as the weight of an arrow increases so the range decreases.

Chart 8.

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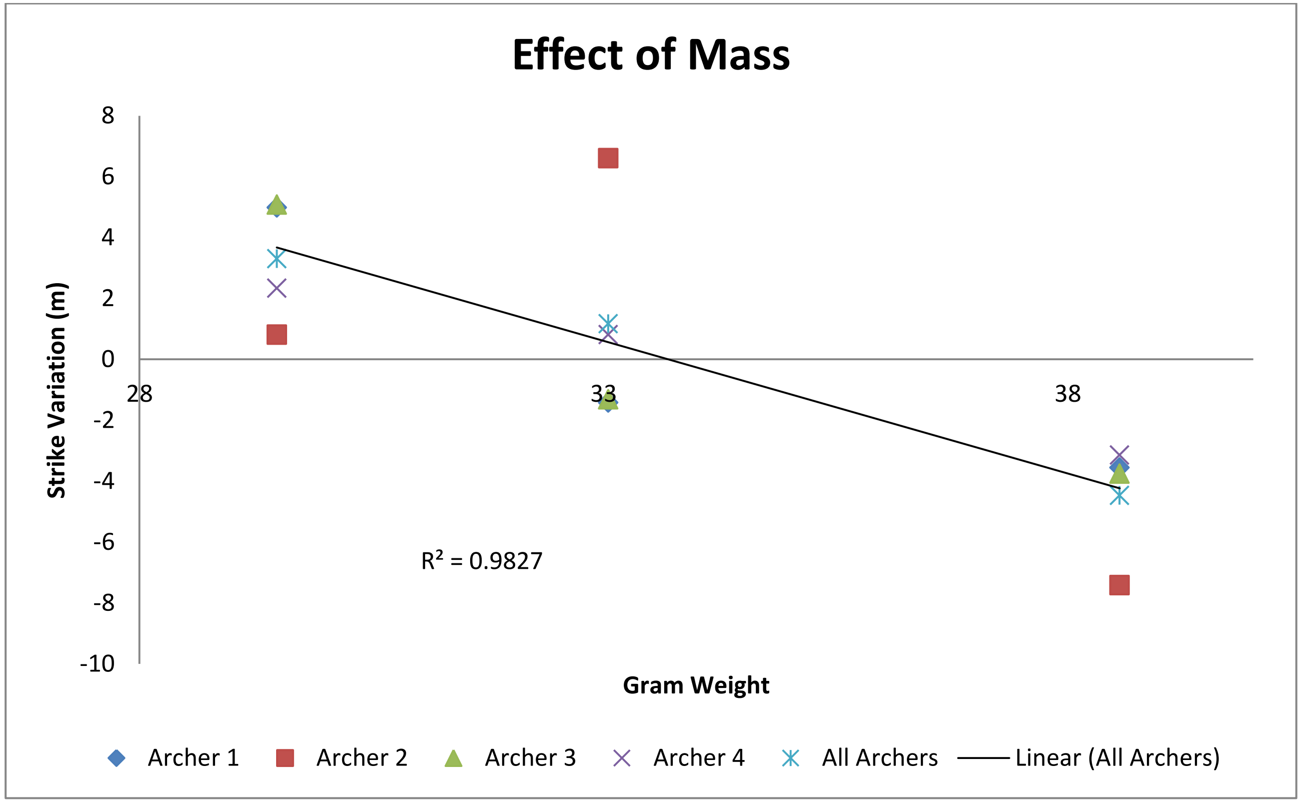
Chart 9.



The Arrows

Common Parameters:

- Release angle - ~45^0.
- ∅ – 11/32”
- Profile – Parallel

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- Spine ≥ 50lb
- Fletch – 4” L/W parabolic bound

Table 7.

Set	Balance Point	Draw Length	Crown Stain	Cock	Hen	Nock	Pile	Weight (gn)	Weight (gm)
288	10¼” behind the pile	29 & 7/8”	Blue	Blue	White	Blue	125gn brass screw bullet	455gn +/- ½%	29.48
168	10 & 5/8” behind the pile	30”	Red	Tre Brown	White	Green	125gn brass screw bullet	510gn +/- 1½%	33.05
289	10¾” behind the pile	29 & 7/8”	Black	Black	White	Black	125gn brass screw bullet	595gn +/- 1½%	38.56

Observations

It is worth noting that the variation in mass was held at what is usually considered to be safe limits for the bow; in this case no lighter than around 9gn/lb draw weight. This was in order to protect the bow and get through a lot of shots without changing the host of variables introduced by needing a replacement.

As might be expected heavier arrows do not travel as far for the same bow weight; an R^2 value very close to 1 suggests either the results were fixed or, as is the case, that there is a high degree of correlation between mass and range. It would be of interest to examine the other direction to see if the point at which energy transfer between bow and arrow becomes inefficient can be determined, because the arrow has insufficient mass to absorb all that the bow delivers, but it is suggested fibreglass or similar bows would be preferred for this as wooden ones are likely to be damaged.

Conclusions

The hypothesis, that as the weight of an arrow increases so the range decreases, may comfortably be held to be true.

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Annex B – Strike Angle

Hypothesis 5 – The arrow will follow a parabolic path in flight, meaning that angle of launch and angle of strike are equal.

Chart 10.

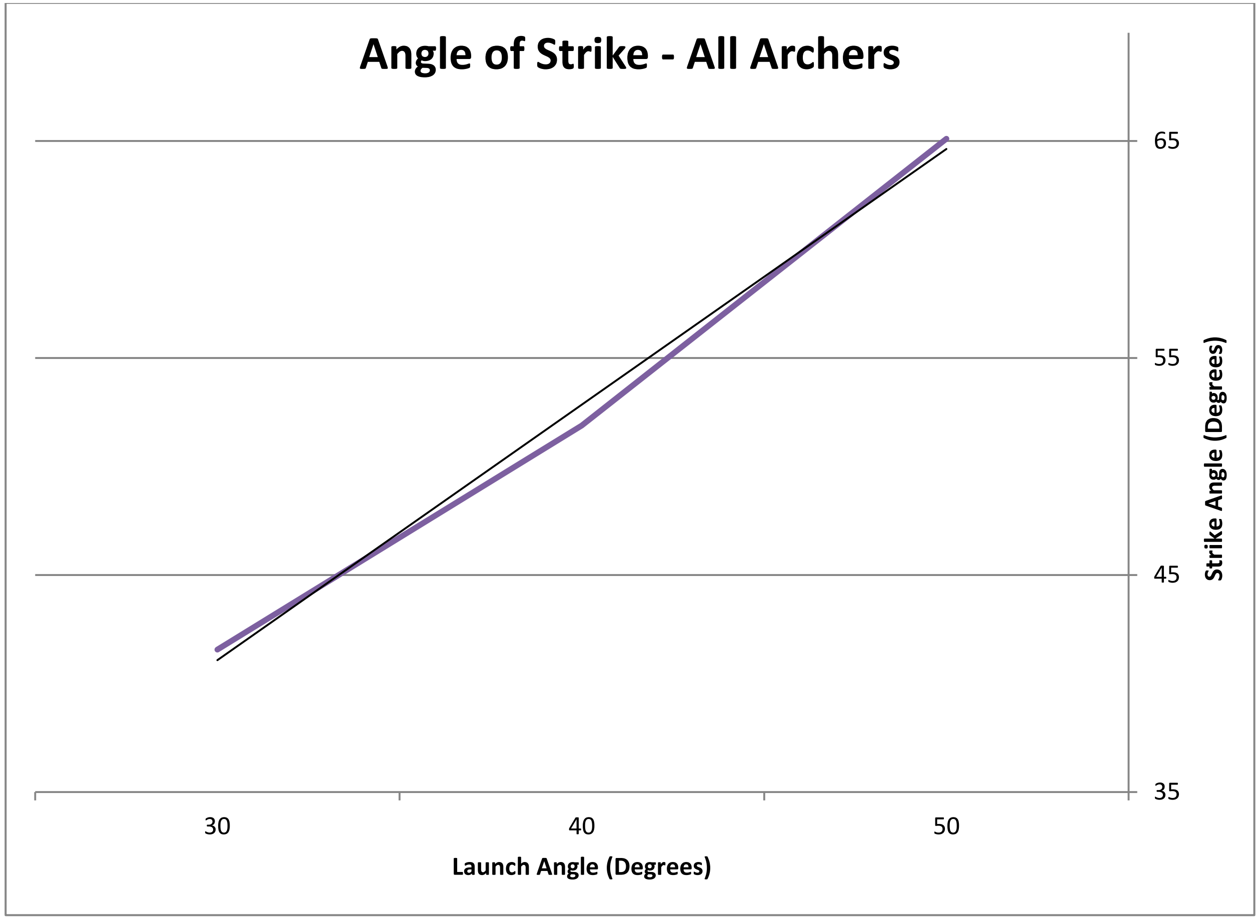

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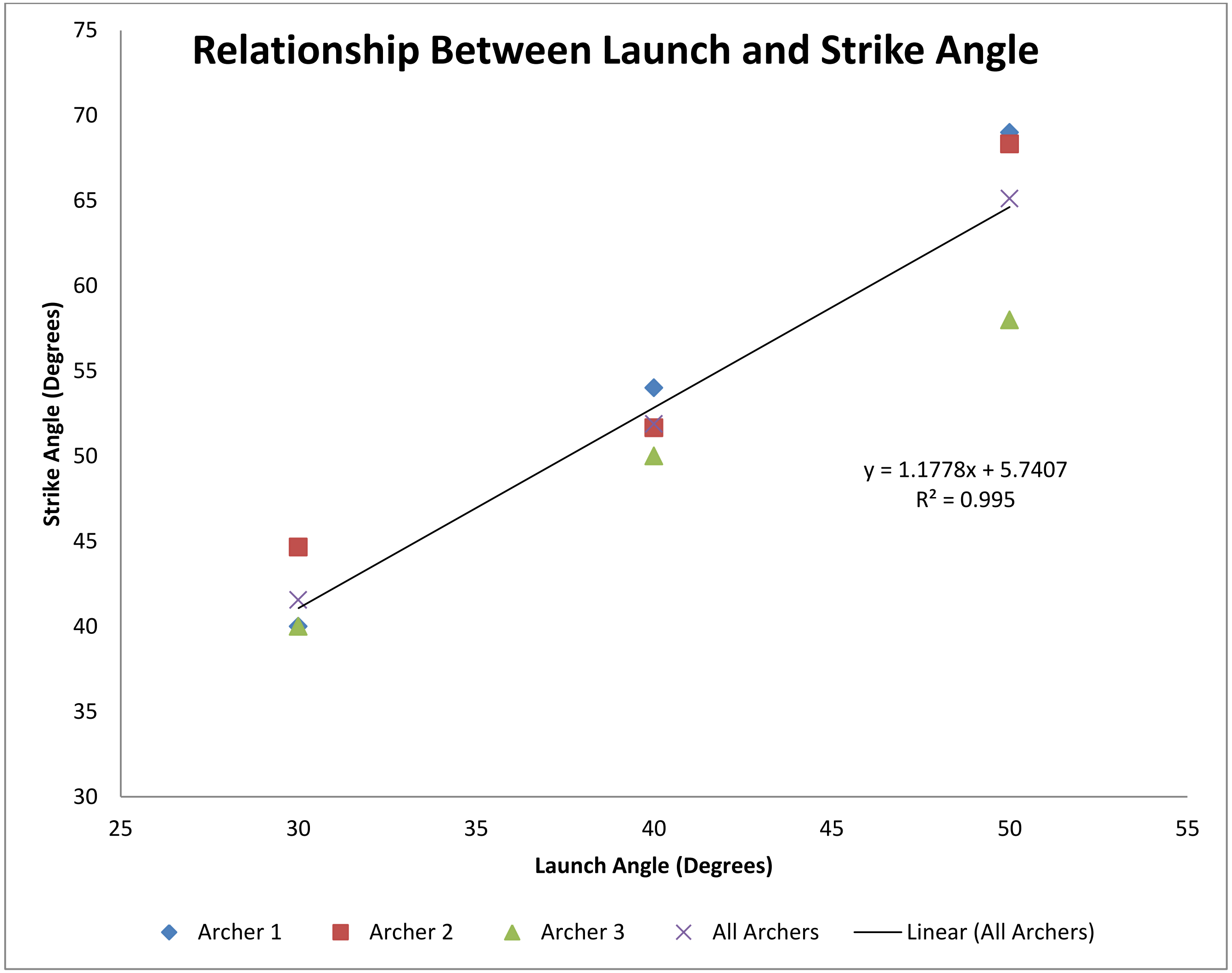
Chart 11.



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The Arrows

A different set of arrows were used for this trial together with a different bow (a flatbow, 45lbs @ 28”). This was to allow for a degree of concurrency; additionally this trail was conducted as a matter of interest rather than contributing to the main examination.

Details of the set as follows:

Table 8.

Balance Point	Draw Length	Spine	Profile	Pile	Weight (gn)	Weight (gm)
12” behind the pile	31”	≥50lb	Bobtail 11/32” to 5/16”	100gn brass screw bullet	Average 560gn	Average 36.29gm

Figure 9.

Observations

There is a high degree of confidence that the results are conclusive, however there seems to be unwillingness within some of the archery community to accept the suggestion that the flight path is anything other than parabolic. Figure 10 provides a simple illustration of parabola and ellipse; it is suggested that no matter how steeply a parabola may be tilted, whilst the launch angle of approximately 45^0 is retained then the observed angle of strike remains consistently too far from this to explain the results. (The difference between strike and launch angle observed is some 12^0 to 15^0.) This suggests the path lies somewhere between a parabola and an ellipse. It would appear that the cone they’re taken from is distorted by the effects of drag; the acceleration due to gravity beyond the apogee is insufficient to compensate for this.

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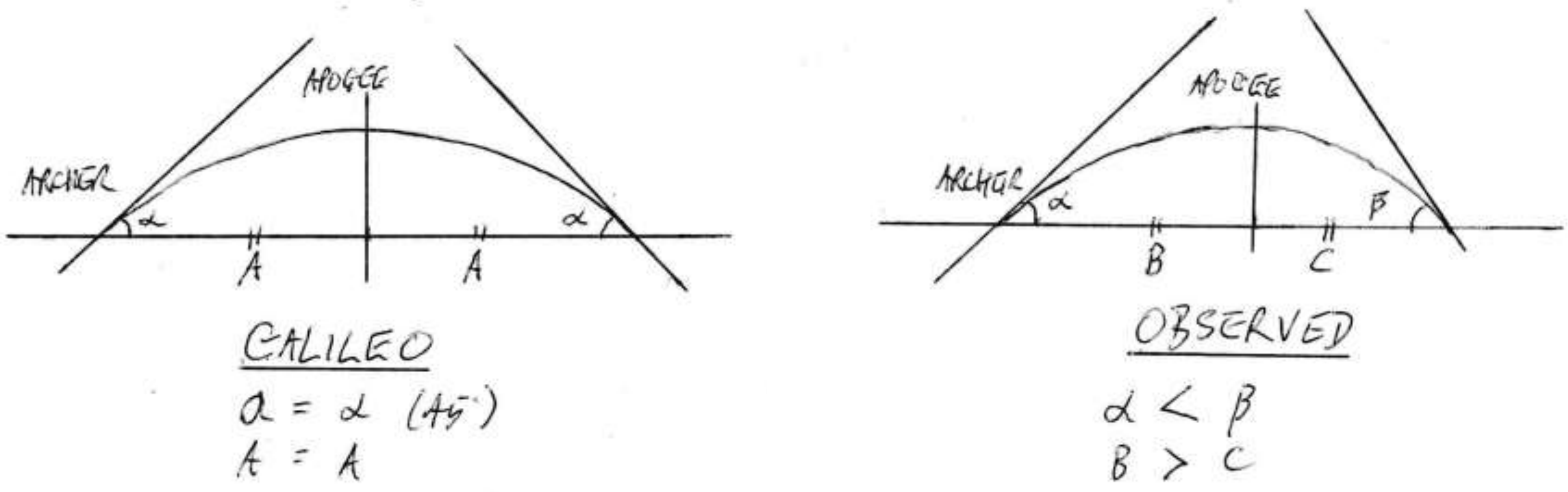
Figure 10.



Conclusion

The hypothesis that an arrow will follow a parabolic path in flight, meaning that angle of launch and angle of strike are equal, is not true. Results obtained indicate that the path lies somewhere between an ellipse and a parabola.

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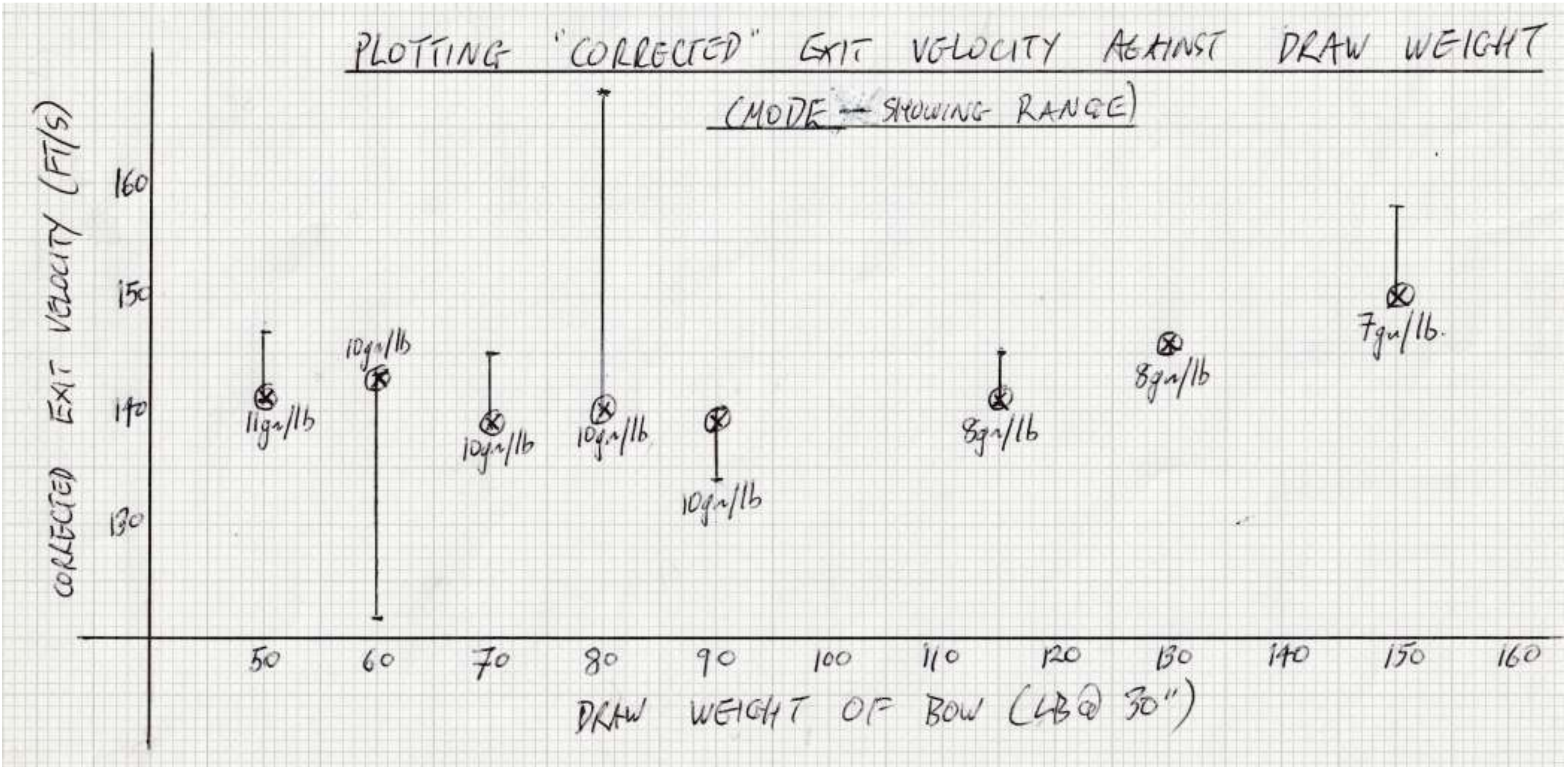
Annex C – Launch (Exit) Velocity Results

Hypothesis 6a – as bow draw weight increases release velocity decreases with the inertia in the bow limbs and the heavier arrow.

Hypothesis 6b – as bow draw weight increases force and energy increases with increased arrow weight.

Chart 12.



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My apologies for the hand-drawn graph. My aptitude with Excel does not include forcing the x-axis to recognise draw weight values as anything other than labels.

Table 9 – The Arrows

Set	Fletch	Spine (lbs)	Diameter (in)	Fulcrum (%)	Weight (gn)	Profile	Fletch Area (in2)	Wood	Bow Weight (lb)	Gn/lb
XP 286	4" Parabolic	65	23/64"	40	550	Bobtail	5.64	Cedar	50	11.00
JW 348	4" Parabolic	70	23/64"	43	610	Bobtail	5.64	Cedar	60	10.17
BS 007	4" Parabolic	70	3/8"	40	680	Bobtail	5.64	Poplar	70	9.71
JW 091	4" Parabolic	90	3/8"	43	800	Bobtail	5.64	Birch	80	10.00
JW 162	4" Parabolic	90	1/2"	44	900	Barrel	5.64	Ash	90	10.00
XP 373	5" Parabolic	160	1/2"	39	1,065	Bobtail	9	Poplar (Tulip)	115	9.26
XP 374	5" Parabolic	160	1/2"	38	995	Bobtail	9	Poplar (Tulip)	140	7.65
XP 375	5" Parabolic	160	1/2"	38	890	Bobtail	9	Poplar (Tulip)	155	5.74

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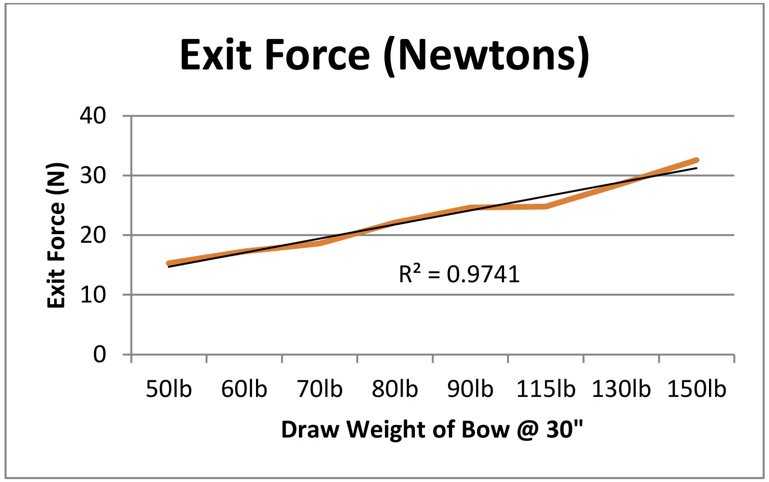
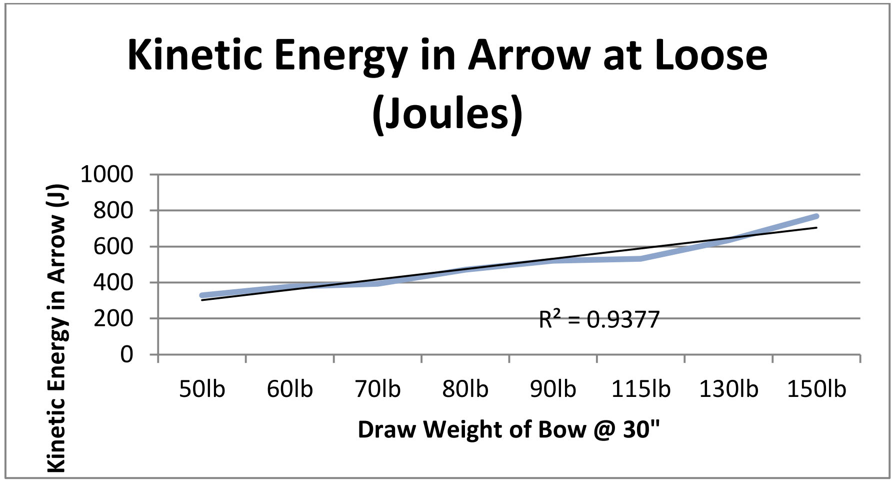
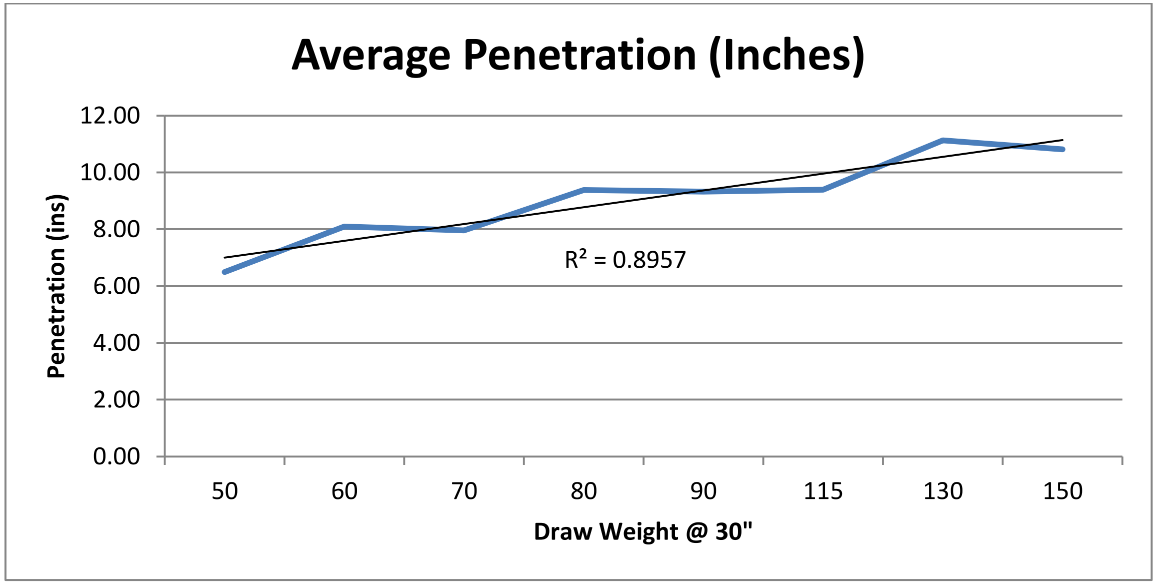
Charts 13 to 15.







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Observations

This set required a slightly different approach owing to a need to support rather more sophisticated work on her doctoral thesis for Abigail Parkes, which is investigating modelling the medieval longbow. Fortunately the work thus far on drag, profile, mass and fulcrum informs this to an extent: this provided an excellent opportunity to investigate the aspect of exit velocities more thoroughly. As illustrated below, Southampton University produced an excellent shooting rig which was designed to go some way towards eliminating archer shooting inconsistencies. The chronometer was placed immediately in front to capture exit speeds, on the presumption that maximum flight velocity will be more or less as the arrow clears the back of the bow. In order to keep groupings tight (not least from inconsistencies between arrows with a set) the range to the target was relatively short at around 20 yards. Additionally penetration of the arrow into the layered foam target was also recorded.

Figure 11.

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The shooting machine proved a very elegant construction; unfortunately owing to the Author's incompetence it wasn't properly nailed to Mother Earth which meant there was some movement as the bow/machine kicked on loose. This was relatively consistent and simply meant that it required realignment after each shot to remain on target. The most obvious effect was however in exit velocities; it was clear those recorded were some 20 ft/s lower than expected owing to induced inefficiencies. To allow for this "free" shots were made using a number of bows at the lower weights (i.e. that the Author could actually draw) and a correcting factor thus established.

The location chosen was at Fort Purbrook, for its proximity to Southampton University. The experiments were conducted over 1st & 2nd September 2022. The weather was fine and wind speed negligible (the shooting range was set up in one of the defensive ditches).

Figure 12.

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As is noted in the Arrows table, the ratio of arrow weight to draw weight drops gradually with the heavier bows. This arose owing to a requirement to use poplar (or, more accurately in this case, tulip wood) for the Mary Rose replica bows i.e. those drawing over 100lb. From earlier results range tends to increase with reduced mass which implies a faster exit from the bow; the slight upward trend is therefore to be expected. Indeed, compared with the higher velocities recorded with lighter bows and more consistently matched arrows the variation recorded lies well within experimental "noise".

The target used was the largest available layered foam boss to best ensure the spread of shot (mostly) landed on it. It was rather a well-used one however and, whilst not quite shot-out, values obtained cannot in any way be taken as absolute. Thereis however a clear trend; as exit force increases so does penetration.

I'd suggest there are two asides to draw from this.

- The military requirement is to achieve the killing effect with the minimum effort. For matched bows and arrows ranges achieved are very similar for a given ratio of arrow weight and draw weight. The driver for equipment selection therefore becomes the lowest draw weight that will achieve the desired effect to both minimise the effort needed to operate it and maximise the number of arrows that can be carried, accepting this is principally a land weapon. Given the work done in Tod's Workshop (Arrows and Armour) the minimum bow weight is clearly going to be significantly greater than 100lbs.
- This also provides a clear illustration of why the longbow was steadily superseded by the arquebus; it doesn't simply seem to be a matter of the training needed to build up the strength and skill required to use a bow of any useful military weight effectively. Black powder weapons allow for a muzzle velocity of between 180m/s to 300m/s (i.e. around 600ft/s to 1,000ft/s, depending on the efficiency of the mix as well as the characteristics of the firearm), over three times that measured for the bows tested[4]. Assuming a ball of around 1 ounce (or just under 440 grains) against an arrow weight of perhaps 2½ ounces for the heaviest bows, the force delivered by a firearm with poor but usable powder is significantly greater than that of the bow, whilst the kinetic energy is over 4 times greater.

[4] Material Culture and Military History: Test-Firing Early Modern Small Arms. Peter Krenn, Paul Kalaus & Bert Hall 1989. See https://journals.lib.unb.ca/index.php/MCR/article/view/17669/22312 .

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Conclusions

Hypothesis 6a – as bow draw weight increases release velocity decreases with the inertia in the bow limbs and the heavier arrow; clearly not the case. Release velocity remains near constant.

Hypothesis 6b – as bow draw weight increases force and energy increases with increased arrow weight. Given near equal exit velocities it is self-evident that this must be true as the mass of the projectile increases, and experimental observations strongly support this.

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Appendix 1 – Experimental Instrumentation.

Shooting Point:

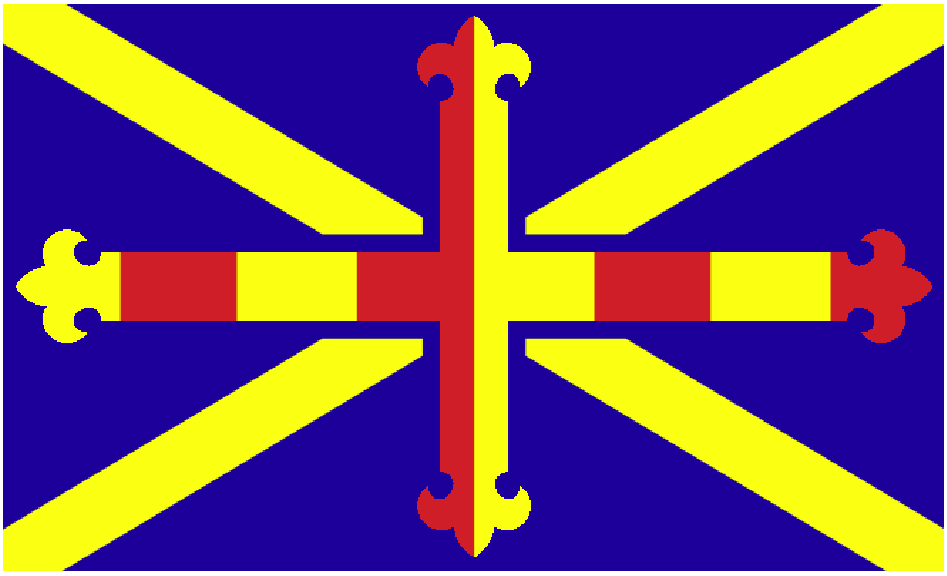
- Flag (for decoration).
- Inclinometer (for consistent angle of loose).
- 50lb @ 30” bow with rubber band (for horizon); experiments 1 to 4.
- 45lb @ 28” bow with its own separate set of arrows for experiment 5.
- Loads of arrows.
- Chronometer/odometer (for release velocity; experiment 6).
- The magnificent shooting machine.

Target Point.

- Laser range finder (for coarse range).
- Flags (for bearing).
- Inspiration, bluff and bluster (for believable results).
- Big piece of paper (for recording results).
- Layered foam target boss (for exit velocity).

Final Observation – Derived Trend Line Equations

The health warning about the statistical analysis is repeated. Additionally it would be unwise in the extreme to build a set of arrows with determined characteristics and assume they will therefore fly a certain distance at a given trajectory. Variations in bow and archer performance will put paid to that, as well as a host of other factors not considered here such as atmospheric conditions. All that it is suggested that we can conclude is that a certain set of characteristics will suit a particular bow and archer for a particular discipline.



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Dedicated to Stephen “Sticky” Green, Gentleman Archer

Aka Captain “Prove It!”

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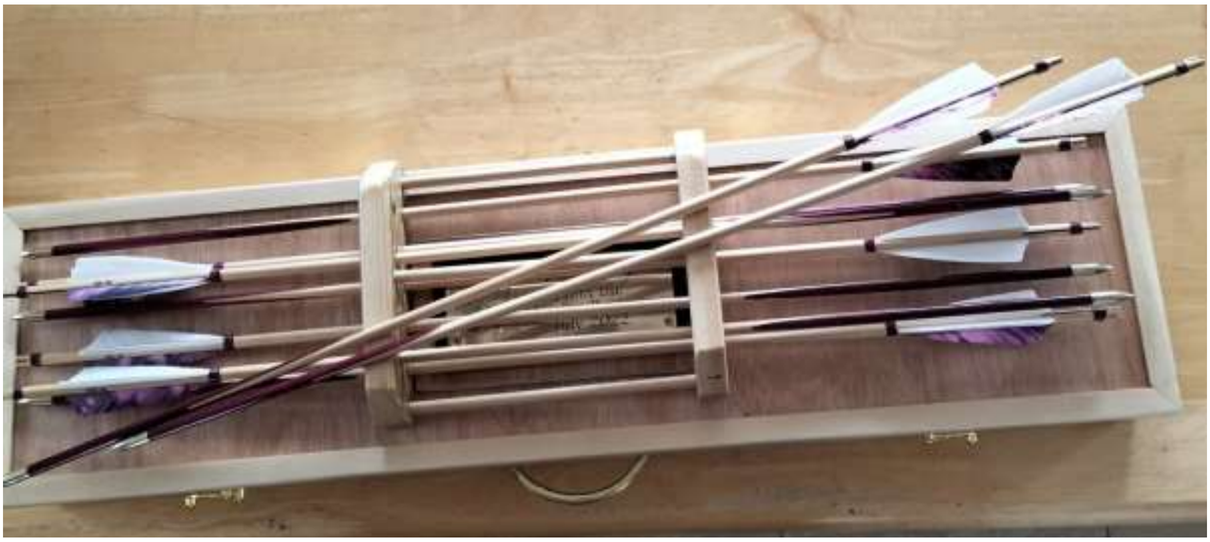
Part II

Design and Build



The following is a sort of everyman's guide, and describes (roughly) the sequence in which I usually tackle a set of arrows. There is no pretence that it is any definitive approach; take from it what you will. I hope there's something in here for most archers.

I've made no attempt to describe the process of making traditional arrows from the plank. That is beyond my competence; I'd suggest consulting the Craft Guild of Bowyers and Fletchers, and Jeremy Spencer has posted an excellent series of videos on U-Tube.

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The first step is to decide what type of shooting is being contemplated, which often means multiple sets of arrows for the bow. From the earlier analysis I've derived the following table which I use as a guide and it generally produces good results:

Table 10 – Characteristics & Purpose (Design)

Type	Weight	Fulcrum	Pile	Fletching/Drag	Profile	Spine
Field/Indoor	~+/- 12gn/lb	Forward	Heavy, field	5" shield, bound	Parallel	Stiff
Short Target	10-12gn/lb	2/5ths behind the pile	Medium, field or bullet	4" shield, bound	Parallel	Stiff
Target	10gn/lb	2/5ths behind the pile	Medium bullet	4" parabolic, bound	Bobtail	Match poundage
Clout	8.5-9.5gn/lb	2/5ths-9/20ths behind the pile	Light bullet	3" parabolic, unbound	Barrel/Bobtail	Match poundage
Flight	6-6.5gn/lb	Close to Centre	Very light bullet	Short & low Hogsback (typically 2¼" x ¼"), unbound	Barrel	Limited by weight; ideally match poundage or more
Popinjay	10-12gn/lb	Forward	Bludgeon	Feather Duster, bound	Blunderbus/Parallel	Stiff

Limitations. At the lightest and heaviest ends of bow weights the physical limitations of wood kick in. Archers shooting the really heavy stuff at around 100lbs or more prefer lighter arrows than the experimental results suggest; generally around 7-8gn/lb (with acknowledgements to Joe Gibbs, Alastair Pinfold and Ian Sturgess). This indicates a limitation on what can be taken from the work done; it was with a 50lb bow for the most part which suggests that the relationship is not linear, certainly as far as mass is concerned. Repeating the experiments with a range of draw weights may well give a wider range of results. At the lighter end it is difficult to source suitable woods for say a 20lb bow shooting clout although where it can be achieved a light bow can reach as far as it's heavier cousin provided the arrows are properly matched.

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Steps (Build)

It is important to appreciate why each step is included in the process. If it is not clear, I'd suggest stopping and working it out otherwise action taken by rote may or may not be right. (When up to your nuts in alligators, it is easy to forget the original idea was to drain the swamp.)

Table 11.

Step	Action	Page
1.	Determine bow draw weight, archer's draw length and type of shooting. Derive finished weight and range of pile weights optional. Calculate start weight of arrow shafts: $$F = \left(\frac{DL}{SL}\right)x + PW$$ Solving for x (preferred start weight of the shaft) where: F = Finished weight of the arrow DL = Draw Length SL = Shaft Length PW = Pile Weight	4
2.	Select shafts & piles.	
3.	Foot shafts if required.	6 & Annex A
4.	Fit piles; shape front end for barrelled shafts.	6
5.	Select nock types: Cut & insert nock inserts (self nocks) Cut nock slots (self nocks) or Seat nocks (do not fit yet) (plastic nocks).	8
6.	Finish shaping shaft to profile.	9
7.	Balance.	9
8.	Shape nock slot for self-nocks.	10
9.	Stain if using a crown stain.	10
10.	Sand down shafts.	10
11.	Self-nocks: Fit cushion (if required) Bind. Plastic nocks: Secure Mask.	10
12.	Varnish undercoat, sand down (fine).	10

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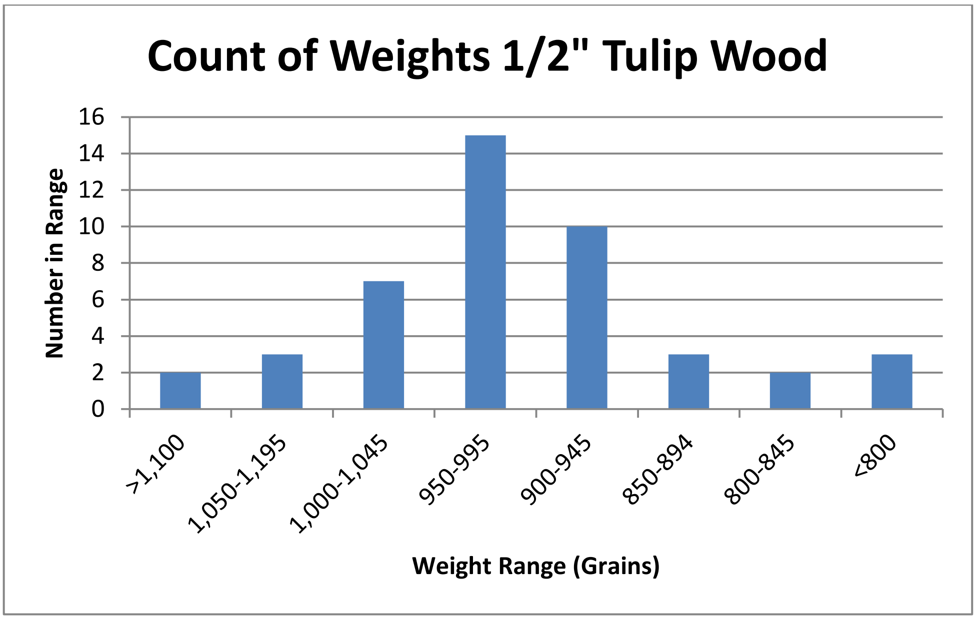
Step	Action	Page
13.	Select fletches for type of shooting (or taste).	13
14.	Fit fletches. Ideally the fletch would be glued directly onto the wood (assuming they're not bound on); fletching at this stage offers a compromise. Sander/sealant usually gives a fairly rough finish which can be awkward to smooth down.	13
15.	Tidy front ends, trim off excess glue.	13
16.	Bind leading edge of fletches if appropriate, varnish fistmele.	13
17.	Varnish, clean off inclusions and runs, weigh.	14
18.	Crest if required.	14
19.	Polish & finish.	14

Steps 1 & 2 – Determining Weights & Shaft & Pile Selection

Shaft Weights

Within any batch of shafts there will be a normal or skewed normal distribution of weights. It may be as much as 20% either way. There is some relationship with spine, in that the stiffer the shaft the heavier it tends to be, but there is no correlation so sets need to be specifically matched for weight at the outset otherwise your arrows won't all go to the same place. Below an example of the range across 45 shafts. The start weight should ideally match but, in the real world, +/- 5% is the outside bracket I'd suggest.

Chart 16.



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I generally use pine, cedar & spruce for the commonest weights of bow which will suffice up to about 55 or 60lb draw weight. This is a limitation on what's available through the archery suppliers who usually stock 5/16" and 11/32" as a matter of course, being the most common requirements and most bows ranging from 35lb to 50lb. 9/32" is available although for some reason it can be difficult to find anything other than pine (Carol Archery specialises in the lighter end of the scale). 23/64" also occasionally appears but I've only seen it in cedar. (Incidentally 23/64" is just 1/64" less than 3/8".)

At 60lb to 70lb draw weights I'll be looking at bought in dowel at 3/8" or 10mm but the rejection rate will be higher; around 20-40%. Poplar and lime usually fit the bill; sometimes birch from the lightest end of the spectrum. For 70+lb to 100lb bows 10mm birch does the job; thereafter for 100lb+ bows I'm looking at 1/2" ash or pine although I do use all sorts and poplar or tulip wood is quite popular amongst the heavy bow folk. There is obviously overlap here; it all depends on the weight and spine of the steles to hand.

Incidentally if I'm asked what wood I'm going to use for a given set the answer will be "I don't know yet" as it all depends on what will fit the bill. Likewise pile weights unless hand forged piles are determined.

There is a convention that the fall of the grain through the shaft should be at least 15" from one side to the other, and that knots should be excluded. This does however relate to fairly light bows; additionally certainly re-enactment arrows are often made with shafts which break the rules. Suffice it to say I would not sell anything in breach of the convention; what I shoot myself is up to me!

Piles

Pile weights will influence the balance point of the set and therefore the longer the range contemplated the lighter the pile should be. It may also be selected to bring the overall arrow weights within the desired weight bracket. Generally typical commercial piles have good tolerances in their weight range; hand forged piles do not. In the latter case varying the weight of the shaft for individual arrows against pile weight will give a good overall weight match, but at the cost of a common balance point for the set.

Example

To bring this together and provide an example; say the draw weight is 50lb, the draw length of the archer 29" and target arrows are required. Assuming a 32" shaft length (standard for most) the calculation is:

$$(50 \times 10) = \left(\frac{29}{32}\right)x + 100$$

This gives a result for *x* of around 440gns; ideally you should seek to match within 10gns (or less).

On Spine

There seems to be quite a lot of rather confusing stuff about; mostly, I think, stemming from a belief that a bow is a bow and therefore what works for an unlimited compound or fibreglass bow with a

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near-centre shelf must therefore work for wooden long and flat bows. They are in fact rather different and require different approaches. I do not speak for the former.

The first point I'd reiterate is that there is a loose relationship between spine and weight, as the stiffer the spine the heavier the stele *tends* to be, but it is not linear and one measure cannot be taken to assume the other. I think this may be what is leading to the perceived need to underspine an arrow for a longbow as it has to bend further around the bow in order to correct for the paradox, whilst fibreglass recurve and compound bows hold the arrow much closer to the centreline. I'd have thought underspining is going to have 2 unwelcome results.

- Accuracy at short range is going to decrease as the arrow will be oscillating laterally more (or yawing). I suppose, with matched underspined arrows, aiming off should correct for this (as we all aim off in any event, to be honest, whether we think about it or not).
- For longer distances the range is going to be scrubbed down as more energy is lost in the yawing, and a greater cross-sectional area is going to be presented thus increasing drag.

What does seem to work (which is how I go about it):

- The measured spine of the arrow needs to be near equal to or greater than the draw weight of the bow at the draw length of the archer. You can get away with a few pounds lighter but this means a good, clean loose is needed. (This is the case particularly with flight arrows for the lighter bows.)
- Where the draw weight and spine index are close, particularly for medium & light bows, the spine of the steles should be matched (to around +/- 10lb, and above the draw weight).
- If grossly overspining (particularly for heavy bows) the spine match becomes increasingly irrelevant.

Having thrown that grenade onto the table before I leave spine I will repeat, from Hugh Soar's excellent book Straight and True, Walter Roth's observation of South American Indians vibrating their shafts and cutting off a few centimetres at a time until the vibrations reduce to a near minimum (presumably judged through experience). European convention demands arrows of the same length (at least to begin with) which rather precludes this approach.

Step 3 – Footing

Rather than clutter the main document up with one method of footing, I've relegated it to Annex A. If you're going to do it though, now's the time!

Steps 4 – Fitting Piles

I start off with this step because it used to be the bit I got wrong most often, and there's usually plenty of stick left if you need to begin again. The exception to this rule (for me) is with blunts if they're going to be crested, in which case blunts are fitted right at the end of the process immediately before final polishing. Begin by measuring off the depth of the pile (the matchstick is my guide – one of the few advantages of smoking) then taper the end down at around 5^0 to this depth. The jig shown was made by Pip Bickerstaffe although you can do it by eye. The pile won't fit fully at this point, swap over to the second gizmo shown to shoulder the seat. Bring it in until the pile does fit then glue on. I use Araldite; leave it a good few hours to cure thoroughly. If you're

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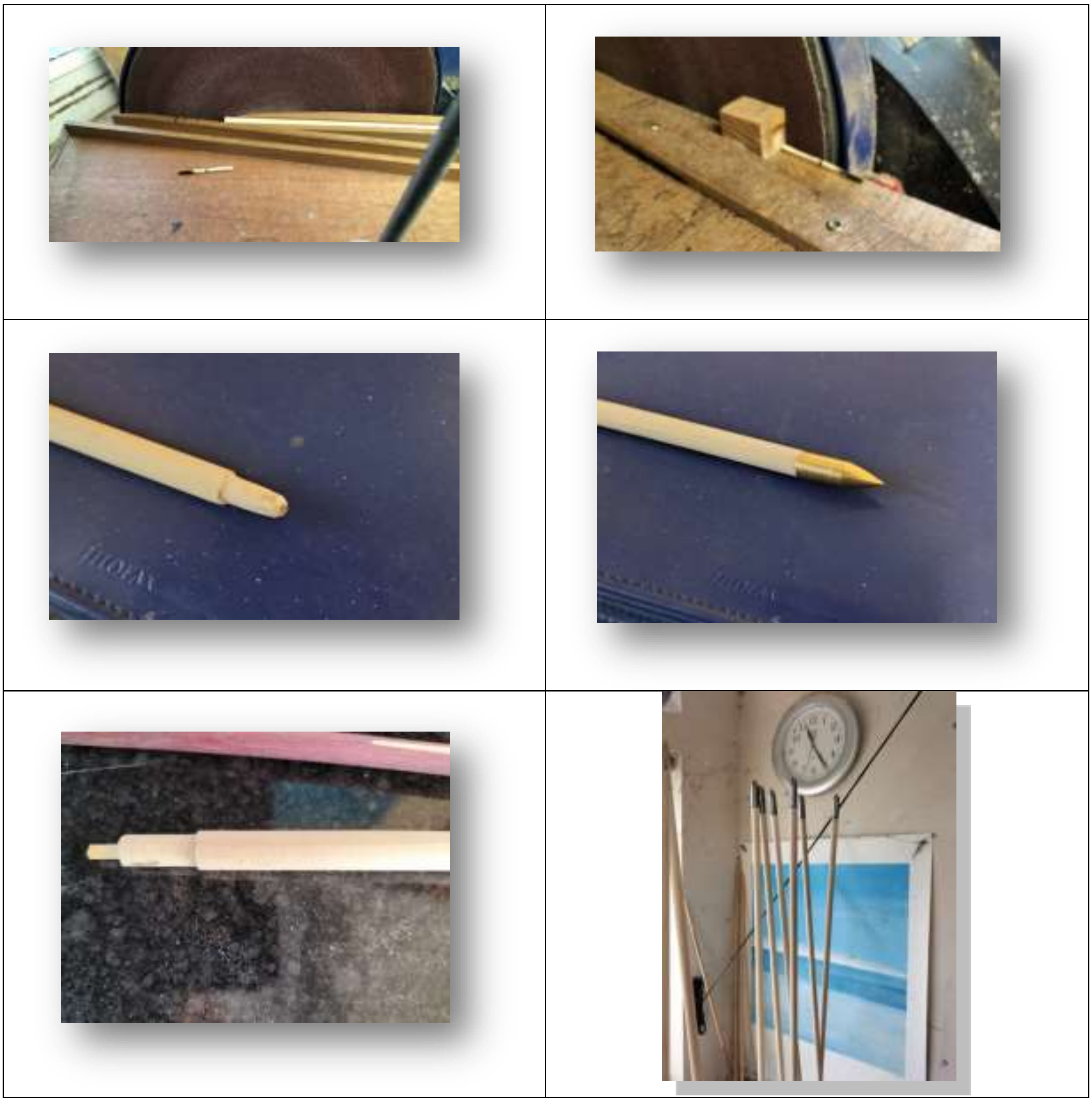
using footed shafts and bladed piles the pile will need to line up with the footing as illustrated in Figure 15.

The second seating illustrated is used for piles made by John Geary which have a parallel stepped fit. The idea is to keep as much wood supporting the pile as practical, and these have two different internal diameters.

Figure 13.



In some instances the pile may be of a smaller diameter than the main shaft, either deliberately or to fit a lighter pile. In this instance shape the seat then taper the shaft in until it fits flush. Keep the taper reasonably steep at the pointy end; usually the arrow will be barrelled and it is ideally tapered more gently at the nock end. (I’ve yet to come across anything that swims or flies with any speed which is broader across the arse than the shoulders.)

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There are several taper tools on the market, designed after pencil sharpeners. The Bearpaw Taper Tool probably gives the most flexibility although it is limited to 23/64" maximum. There isn't one that shoulders the pile that I'm aware of.

Tanged piles require the hole needed to receive the tang drilling out first, then shaping to get a flush fit with the pile itself. They're fundamentally quite weak so need binding in once glued (binding as with self-nocks below – see Figure 20).

Figure 14.

Step 5 – Nocks

Decide on the depth of the nock slot, add this to the draw length then cut shafts to this length. A point of no return…

The orientation of the insert (which is effectively a load spreader) is shown in Figure 15; i.e. with the grain. An insert isn't always used but, like so much of this, protects both bow and arrow. It is usually taken to a depth of around 2½" or so. I use 1mm modeller's Plasticard for this; it doesn't have a grain and as a long chain hydrocarbon is good under both compression and tension. 1mm also happens to be the width of my bandsaw blade. If you're using a footed shaft then the insert needs to line up with the ears which may not be directly in line with the grain as this will often spiral down the length of the shaft; similarly the nock slot should be sighted into the bottom of the Vee and remain at right angles to the insert.

Whatever you decide to use cut the slot, glue the insert in place and allow to dry, ideally clamped tight as shown. Superglue works well, as does wood glue although this takes considerably longer to cure. Once dry (& cured) cut off the excess insert and cut out the nock slot itself. (Bow trainer photo-bombed by Phil Kearey; phil95wrx@hotmail.co.uk.)

Bearpaw (naturally) have a tool on the market, the Bearpaw Self Nocker Plus. It is limited to 23/64" shafts maximum; if you're not doing too many and like to have lots of gadgets about it may suit.

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Figure 15.

Fit-On Nocks.

Glue on nocks add to the arrow's draw length; unfortunately just how much needs to be checked for each new batch of nocks even if from the same manufacturer. Take a piece of dowel of known length, shape the seating, dry fit a nock and measure the new length. Deduct the difference from the draw length required and cut to this, then shape the seating on the main batch.

Steps 6 & 7 – Profiling & Balancing

Bobtailing and barrelling differ slightly from the descriptions provided by Keith Watson in Figure 8.81, Weapons of Warre, in that the taper at the fistmele is only over the last third or so of the stele, a limitation of the length of the belt sander used.

Using either basic callipers or the nock to be fitted, sand down to the required diameter. Use a gentle angle at this end of the arrow. Can be done on a sanding belt, by hand or use a jig similar to that for footed arrows noted in Annex A.

At this point balance the set; rest them on a dowel and roll it until they tip. If the tipping point is over too wide a spread sand the last third down further taking care to maintain the profile.

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Figure 16.

Steps 8 to 12 – Shaping Nocks to Undercoating

For self-nocks the initial crude nock cut requires sanding into shape. It needs to be wide enough to fit into the fletching jig and sharp edges removed to protect the bowstring. It should be slightly wider at the base of the valley to grip the bowstring. The simplest way of doing this is to use a 3mm drill bit at the base of the nock; additionally when they're dipped the varnish naturally collects at a point assisting the grip.

Figure 17.

.

At this point surfaces should be free of glue and therefore is at the last point where the wood will take an even(ish) stain. I use water based stains as they leave the grain visible. It is as well to leave the stained shafts overnight before sanding down. Little Dipper comes into its own, although an

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empty ½ litre coke bottle stains to roughly the right depth. If all stains are not exactly the same length this will be tidied up at the cresting stage.

Figure 18.

The shafts should be sanded down at this point, to remove thumb-prints and other marks as well as smoothing off and keying the surface. Grit depends on the wood (e.g. for ash I usually start with 40 grit) but 80 followed by 120 does for most jobs.

For self-nocked arrows and bows at 70lb or greater draw weight I also fit a leather cushion into the base of the nock at this point. It also serves to protect both bow and arrow. Glue and clamp in a leather strip, about 1/8" wide, then trim flush with the stele surface once it's dried.

Figure 19.

Whilst not strictly necessary binding just below the nock cut serves to reinforce the arrow further. The easiest stuff to use is waxed cotton, bought by the metre. Nylon thread (bought by the kilometre) will also do the job but I'd advise adding more turns. The number of turns is arbitrary; for

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the former I use 7 for the 7 samurai and for the latter 12 for the 12 apostles. Once complete and tied off run superglue over the binding surface to make sure it stays there.

Figure 20.

Plastic nocks are mercifully simple in comparison. Fletching glue such as Saunders NPV works exceptionally well for this; superglue and HMG are a little brittle in my experience. Ensure the nock is oriented correctly against the grain (as with a self-nock). If using indexed nocks this also needs to be properly positioned for either a right or left handed archer (see below under fletching). Allow the glue to dry; a couple of hours is good despite what it says on the tube, then mask up otherwise you'll have splodges of varnish all over the nock.

I start varnishing with a sander/sealer such as Clostermans as it gives a smoother surface for the final coat of varnish or lacquer to adhere to. Self nocks require a 2 stage approach; firstly dip the nock end to give you something to hold onto and allow that to dry. Once done, dip, paint or whatever the remainder of the shaft. Plastic nocked steles can obviously be coated in one step. Many of these products aren't particularly conducive to good health, so I exhort you to buy and use a decent mask.

Time For A Break

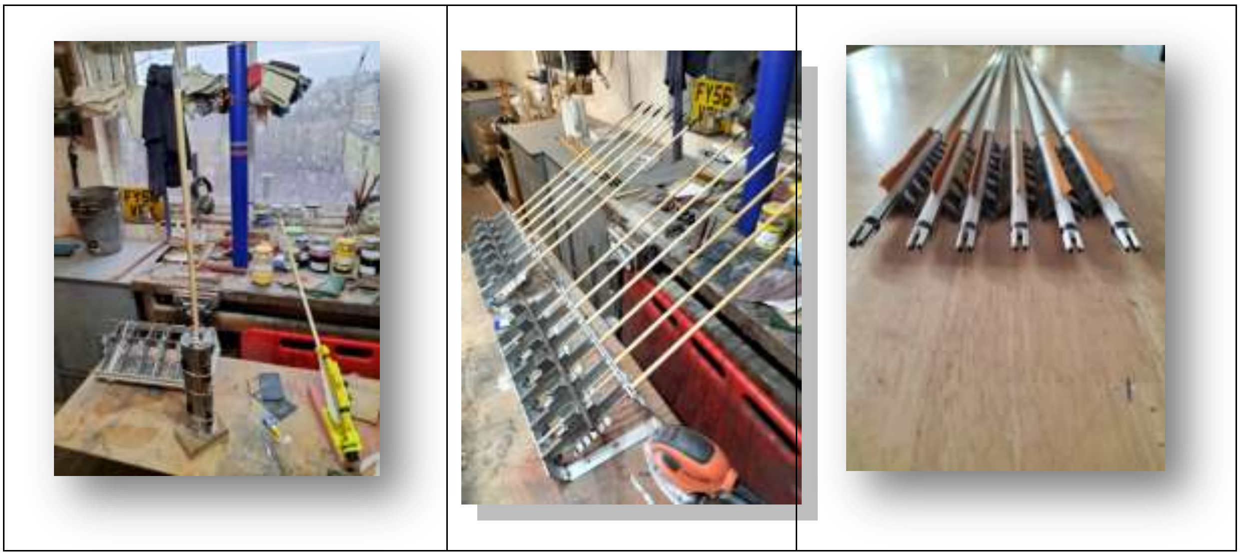
Steps 13 to 16 – Fletching Up

First sand down again, this time I usually use 120 & 400 grit.

Before setting the shafts in the fletching jig check whether the archer is right or left handed. The grain in the arrow will almost invariably fall away from the centreline; if there's a hairline crack in it or it's grossly underspined it can break in the bow. If it does they'll usually be two sharp bits either side of the break; the idea is that the one passing over the bow hand should have the sharp bit pointing towards you for obvious reasons.

The finished arrow looks considerably better if most of the rachis is ground off before gluing to the shaft & it also makes for a better contact. To avoid carpel tunnel syndrome I suggest something like an 80 grit pad in a corner sander; this does mean the fletch needs securing in a metal clamp for this step. Sand down as far as you dare – you'll trash a couple of fletches working out where this is. (A good reason for never starting with exactly the number of feathers you think you'll need.) The most effective glue I've found to be HMG; it's a little stiffer when dry than the fletching cements on the market but that makes it much easier to trim off excess glue when all the fletches are done. Despite the 10 minute drying time claimed on the packaging I'd suggest leaving in the clamps for 1½ to 2 hours (and longer in the winter) which means being able to attach more than one fletch at a time is a real bonus. Note that Asiatic pattern arrows are fletched at 90^0 to the conventional western arrangement; usually all 3 fletches are also the same colour.

Figure 21.



When done and sprung trim off excess glue from the sides of the fletches then tidy up the leading edges so that they do not catch when run over a finger. (This precludes the need for a shooting glove in most instances.) Apply a dab of glue to the front of the rachis then, if required, bind as with the nock binding. Varnish the fistmele; this also strengthens the bond with the fletches. Best applied with a brush.

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Steps 17 to 19 – Finishing Off (finally)

Next step is to varnish the remainder of the shaft and allow to dry. When done, check for runs and inclusions and clean these off using something like 180 grit wet & dry; check weights. I don't intend to go into cresting in any detail; suffice it to say it's usually used to identify an individual's arrows and/or to tidy up the boundary between crown dipping or staining and the remainder of the arrow. The nicest jig I've come across is made by Julian Coleman; julian@cityaudioservices.com.

Figure 22.

The final steps are cleaning excess varnish off the piles using a wire brush then polishing them using a 2 or 3 stage approach, (I'll usually sharpen hand forged piles with an edge at this point), then polishing the main shaft with a beeswax based furniture polish. Gives a nice finish for a brief while. All done on a drill using standard polishing wheels and grit.

Now go break or lose them!

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Annex A & Step 3 – Footing.

Figure 23.

Originally used to repair a broken shaft, the Victorians seem to have turned this into an art form. I mostly use it for repairs.

At this point you'll have chosen shafts and piles. The simplest way to foot is to begin with a slightly oversize square billet, 8-10" long, and cut a slot in it around 4½" deep. This should be at 90^0 to the grain. The billets should be weight matched; bear in mind that most of the wood will end up on the workshop floor so the actual weight chosen is not that critical. I've used mahogany, sapele, purpleheart, ebony and oak to date.

Mark a point about 4" from the end of the shaft you're going to foot then, working with the grain, shape this into a wedge. Keep the full length of the shaft if you're footing new arrows. Don't bring the pointy bit in too fine otherwise there'll be a gap at the bottom of the join. Clean off guide marks, insert into the billet secured with superglue or wood glue, and clamp. A metal bench vice is really useful for this bit.

Once dry and secure clean off the bulky part of the ears, ideally with a belt sander, then use a shooting board and one-handed plane to circle the square. Using a drill (on its lowest torque setting) feed into sandpaper fixed at the correct taper until you have a smooth shaft ready to cut and fit the piles. (The jig illustrated, also made by Pip Bickerstaffe, is simply 2 blocks of wood with

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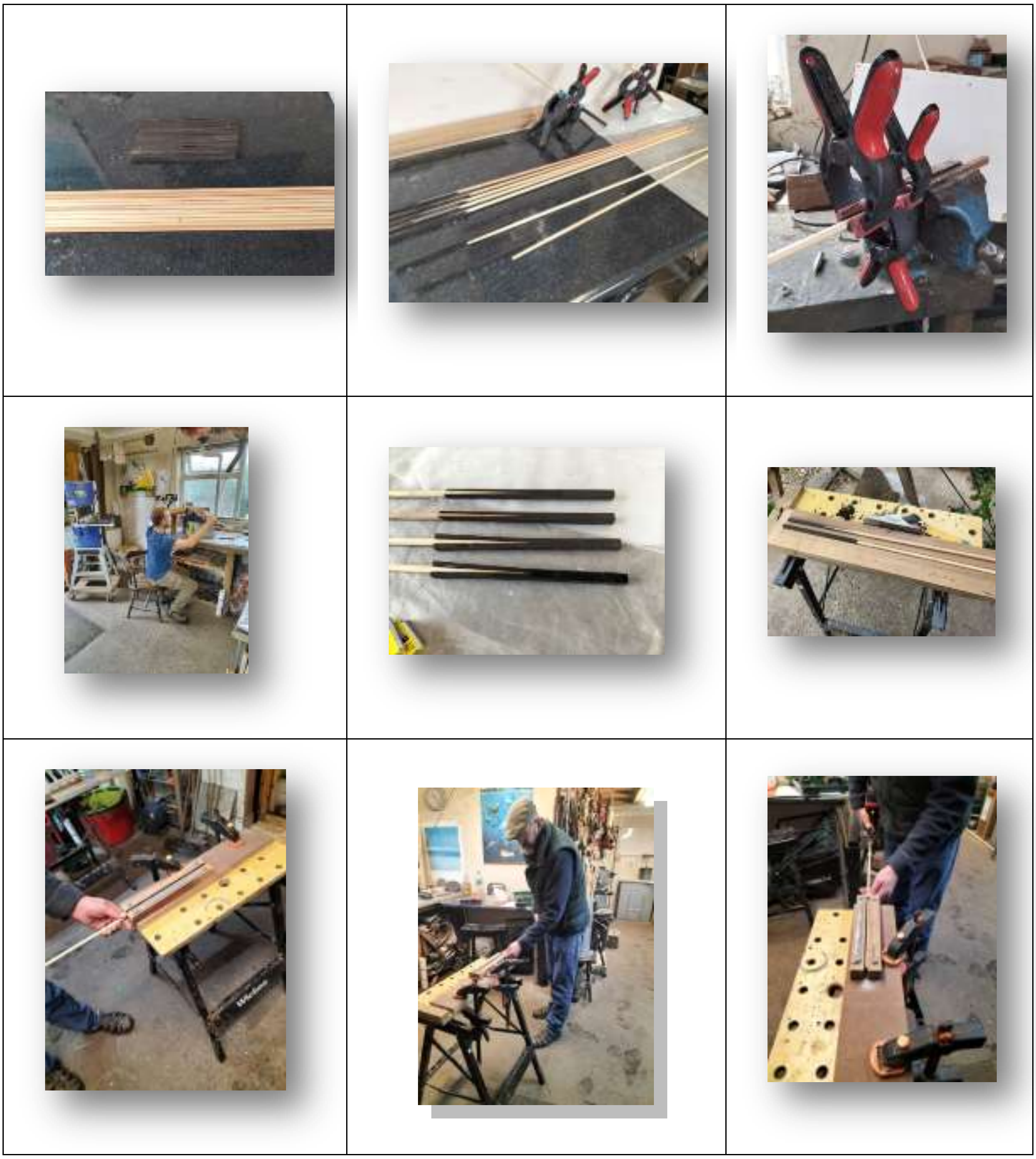
coarse sandpaper glued on the inside. One block is adjustable through a couple of bolts.) Conventionally the ears should be the same length across the set. Abracadabra; on to Step 4.

Figure 24.



Working with repairs requires a different approach. Unless you're going to refletch the whole thing and take a risk with breaking the shaft in the drill a bolder approach is needed. Sort the billets, wedge and glue up as before, then cut off any excess from the front of the footing (remembering to allow for the pile), and sand off the excess. Shape with the plane then I do all the rounding on the sanding belt, judging by eye. This often results in a slightly slab-sided front end to the stele as you're

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working soft and hard woods together but it does give you a usable arrow back. I've several arrows that have been footed multiple times – never give up!

And you can always crown a broken nock, or indeed waist a broken stele.

Figure 25.

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