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Air-shaft Alignments in the Great Pyramid

John A.R. Legon

In recent articles detailing the results of Rudolf Gantenbrink's investigation of the air-shafts in the Great Pyramid, Robert Bauval has provided new values for the angles of shafts, and has put forward revised estimates for the dates of the conjectured stellar alignments.[1] Calculations employing the rigorous formulae for the precession of the earth's axis of rotation have shown, however, that some of Bauval's findings are far from accurate; and it is evident that some dates were obtained using a computer program which was never intended to calculate accurate positions for stars over long periods of time.[2] In particular, this program ignores the effect known as 'proper motion', which in the case of the star Sirius is quite considerable and alters the computed date of alignment by about 500 years.

Since definitive values for the angles of the shafts have yet to be published, it seems best to provide a table by means of which any future statements can be evaluated. In Table I, therefore, the output from the writer's own precessional calculation program has been reproduced for the three stars considered by Bauval to have been significant. The results take account of proper motion and use the latest refinements in the precessional formulae;[3] they have been checked using the data published by astronomers specializing in astro-archaeology, in a catalogue listing the positions of the brightest stars at intervals back to 10,000 B.C.[4] A comparison between the two sets of data has shown differences in the computed declinations of less than 0.01°, or well within the limits of accuracy of the catalogue which was estimated to be ±0.02° at 2500 B.C.

The declination values in Table I represent the angular distances of the stars above or below the celestial equator, which intersects the meridian at an altitude given by the complement of the observer's latitude. The altitudes of the stars as they crossed the meridian at culmination can consequently be computed as shown, for the latitude of the Great Pyramid of 29° 58' 51" north. With a slight correction for atmospheric refraction,[5] these altitudes indicate the angles with which the shafts in the Great Pyramid would have had to be constructed, in order to obtain alignments with the stars when culminating at the respective dates.

Starting with the shafts from the King's Chamber, Bauval suggests that the southern shaft was directed towards the star Zeta Orionis or Alnitak -

SIRIUS			ALNITAK			THUBAN		
Date	Dec.	Alt.	Date	Dec.	Alt.	Date	Dec.	Alt.
-2800	-21° 49'	38° 12'	-2700	-16° 3'	43° 58'	-2700	89° 27'	30° 32'
-2750	-21° 39'	38° 22'	-2675	-15° 55'	44° 6'	-2675	89° 18'	30° 41'
-2700	-21° 29'	38° 32'	-2650	-15° 48'	44° 13'	-2650	89° 10'	30° 49'
-2650	-21° 19'	38° 42'	-2625	-15° 40'	44° 21'	-2625	89° 2'	30° 57'
-2600	-21° 9'	38° 52'	-2600	-15° 33'	44° 28'	-2600	88° 53'	31° 6'
-2550	-21° 0'	39° 1'	-2575	-15° 26'	44° 35'	-2575	88° 45'	31° 14'
-2500	-20° 50'	39° 11'	-2550	-15° 18'	44° 43'	-2550	88° 36'	31° 23'
-2450	-20° 41'	39° 20'	-2525	-15° 11'	44° 50'	-2525	88° 28'	31° 31'
-2400	-20° 32'	39° 29'	-2500	-15° 4'	44° 57'	-2500	88° 19'	31° 40'
-2350	-20° 23'	39° 38'	-2475	-14° 56'	45° 5'	-2475	88° 11'	31° 48'
-2300	-20° 14'	39° 47'	-2450	-14° 49'	45° 12'	-2450	88° 3'	31° 56'
-2250	-20° 5'	39° 56'	-2425	-14° 42'	45° 19'	-2425	87° 54'	32° 5'
-2200	-19° 56'	40° 5'	-2400	-14° 34'	45° 27'	-2400	87° 46'	32° 13'
-2150	-19° 48'	40° 13'	-2375	-14° 27'	45° 34'	-2375	87° 37'	32° 22'
-2100	-19° 40'	40° 21'	-2350	-14° 20'	45° 41'	-2350	87° 29'	32° 30'
-2050	-19° 31'	40° 30'	-2325	-14° 13'	45° 48'	-2325	87° 20'	32° 39'
-2000	-19° 23'	40° 38'	-2300	-14° 6'	45° 55'	-2300	87° 12'	32° 47'

Table I. Declinations of Stars, and Altitudes at Culmination for the latitude of the Great Pyramid.

this star being singled out in preference to the two other stars in Orion's Belt, because it gives a date of alignment closest to the assumed date of construction of the Great Pyramid. It is worth noting that contrary to the impression given by Bauval, Alexander Badawy never referred to the stars in Orion's Belt in his study of the shafts, and clearly believed that the star named *S3ḥ* in the Pyramid Texts was Alpha Orionis, or Betelgeuse.[6] In the present writer's opinion it was probably Beta Orionis or Rigel - an equally brilliant star and a worthy companion for Sirius - but in neither case would alignments with the shafts have been possible. Taking the angle of 45° 0' as stated by Bauval for the southern shaft, however, it will be seen from Table I that an alignment with Alnitak occurred between 2500 and 2475 B.C., giving an agreement with Bauval's date of c. 2475 B.C. in this instance because the proper motion of Alnitak is small enough to be neglected.

As regards the northern air-shaft from the King's Chamber, the mean angle of slope was estimated by Petrie to be about 31°;[7] and the shaft is therefore supposed to have been aligned towards the north celestial pole, the altitude of which is about 30° at the latitude of the Great Pyramid. According to Bauval, however, the latest measurements give an angle of slope of 32° 28' 16", and an alignment was made towards the former pole star Thuban, or Alpha Draconis, in about 2425 B.C. Assuming that this alignment was intended, the correct date as shown by the data in Table I is in fact around 2350 B.C., or more than 125 years after the alignment occurred between Alnitak and the southern shaft.

Now turning to the shafts leading from the Queen's Chamber, Bauval states that the southern shaft has an angle of 40° 0', and claims that an alignment with Sirius took place in about 2450 B.C. It so happens that this date is exactly the mean of those given by Bauval for the alignments with Alnitak and Thuban;[8] yet as reference to Table I will show, the alignment with Sirius actually took place in around 2200 B.C. It seems reasonable to conclude, therefore, that this shaft could not possibly have been sighted towards Sirius during the period of construction of the Great Pyramid.

It is clear, in any case, that no single date can be determined for the various alignments of the shafts in the Great Pyramid, besides which the variations in the angles of the shafts themselves makes it impossible to fix an accurate date for the alignment of any one shaft. Employing a theodolite to sight down the air-shafts from the King's Chamber, Petrie observed that the angle of the northern shaft increased towards the outside of the pyramid from 30° 43' to 32° 4', while the angle of the southern shaft increased from

44° 26' to 45° 30'.[9] These variations result in uncertainties in the dates of the supposed stellar alignments of about ±100 years.

According to the theory that the northern air-shaft from the Queen's Chamber was constructed as a substitute or 'model' entrance passage, the slope of this shaft might either have been set about equal to that of the actual entrance passage, or else have been chosen to give an alignment towards the north celestial pole. The angle of slope should thus have been about 26.5° or 30°. In fact, however, the slope is about 38°; and for this reason Bauval has suggested only that the shaft was directed 'well into the circumpolar region of the sky', or towards 'Draconis's centre'.[10] It is therefore evident that no precise astronomical or cultic significance can be assigned to this northern shaft; and we must also note that if the Queen's Chamber had preceded the King's Chamber as the intended burial place in the Great Pyramid, then the direction of the southern shaft would also be brought into question. It should in this case have been aligned to some star in the constellation of Orion, and not towards Sirius. As the present writer has already shown,[11] however, the angles of both shafts from the Queen's Chamber can be explained very easily as having provided the shortest route to the outside of the Great Pyramid; and since this chamber is situated in the centre of the pyramid, the two shafts would also have emerged at the same level on the north and south sides. This symmetrical and most practical design is consistent with the writer's view that the shafts were constructed simply as ventilation channels.

Now as regards this interpretation, we must refute Badawy's contention that the shafts would have been laid horizontally if they had been intended as ventilation channels,[12] since in this case the lengths of the shafts would have been nearly doubled, while the up-draught of hot air obtained through sloping shafts by convention would have been nullified. With sloping shafts, the temperature differential between the north- and south-facing sides of the Great Pyramid could in itself have caused a convection current to be set up, allowing cool air to be drawn down through the northern shaft while warmer air exited from the southern shaft. The idea of employing north- and south-facing outlets may have been suggested to the builders by their experience of the strong air currents which flow through the connected northern and western passage-systems in the Bent Pyramid;[13] and as previously noted,[14] the ascending passages in the Great Pyramid would have presented a problem because hot spent air would have risen to the upper chambers, making it difficult to breath and to keep oil-lamps alight owing to the lack of oxygen.

Although the angle of the air-shafts leading from the Queen's Chamber did not have to be set accurately for the purpose of ventilation, the geometrical solution put forward for this angle by the writer on the basis of Petrie's measurements - that the shafts should take the shortest route to the outside of the pyramid - may now be modified in the light of Gantenbrink's data. Whether or not the pyramid-architect realised that the shortest distance to the outside of the pyramid from a given point inside could be found simply by taking the inverse of the casing-angle, he was not bound to employ this knowledge; and we have seen that the angles of the shafts leading from the King's Chamber were adjusted to compensate for the offset of this chamber to the south of the pyramid's centre, so that the outlets were placed at exactly the same level of 150 cubits above the base on both the north and south sides.[15] The question, therefore, is whether a level was chosen for the outlets of the shafts from the Queen's Chamber, which would explain the adjustment in angle from the theoretical value of about 38° - as indicated by Petrie's measures at the lower ends of the shafts - to the value of 40° 0' as given by Gantenbrink for the southern shaft.

We need not doubt that the architect could have determined in advance where the shafts would emerge in the outer casing of the pyramid, since a graphical method appropriate to the solution of this problem was discovered by Petrie *in situ* at the mastaba no. 17 at Meydum.[16] Here, construction lines were drawn on white-plastered sections of mud-brick wall to show where the sloping sides of the mastaba had to be founded on the sloping rock, to give the intended dimensions at base level. Alternatively, the points of emergence of the air-shafts could have been calculated using an adaptation of the *aha* or 'rising-up' problems in the Rhind Papyrus[17] (fig.1). Given the distance from the foot of the shaft horizontally to the face of the pyramid, the slope of the casing of 14:11, and the inverse slope as the shaft-angle, the problem would have taken the form: ***14/11 of a rising-up and 11/14 of it, added to it, is equal to the given distance. What is the rising-up?*** The gradients 11/14 and 14/11 being expressed in unit fractions as '2 '4 '28 and 1 '6 '11 '66, the solution would have been found by adding these fractions together and dividing the result into the given distance.

Applying this calculation using Gantenbrink's shaft-angle of 40° 0', and remembering that the shafts from the King's Chamber terminated with short horizontal sections, it is possible to show that the shafts from the Queen's Chamber would have come out in the 90th course of the casing, if they had been continued. This course defines one of the remarkable 'stages' in the core-masonry of the Great Pyramid, being markedly thicker than any of the

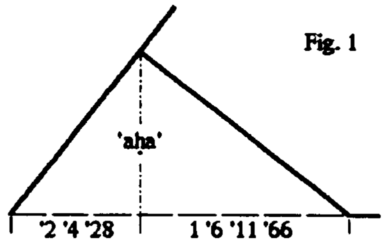

Fig. 1

preceding 44 courses; and as shown by Petrie's measures, it is 2711.1 inches or 131.5 cubits above pavement-level. Whereas the King's Chamber was placed at the level in the pyramid at which the diagonals of the horizontal cross-section are equal to the sides of the base, or just 440 cubits,[18] the diagonals at the level of the 90th course are exactly equal to three-quarters of the side of base, or 330 cubits; and thus the angles of the shafts can once again be explained, not by stellar alignments for which no convincing results can be obtained, but by geometrical factors of the type already established in the internal design of the Great Pyramid.

1. R.G. Bauval, D.E. 26 (1993), 5-6; D.E. 27 (1993), 5-7.
2. The program Skyglobe. Bauval had earlier obtained accurate dates using a programmable calculator. See D.E. 13 (1989) 7-18; D.E. 16 (1990) 21-27.
3. Explanatory Supplement to the Astronomical Almanac (1992), 99-105.
4. G.S. Hawkins and S.K. Rosenthal, '5,000- and 10,000-Year Star Catalogs', Smithsonian Contributions to Astrophysics, Vol.10, No.2 (1967), 141 ff.
5. Refraction would have increased the observed altitudes of the stars in question by between one and two minutes of arc.
6. A. Badaway, Mitt. Inst. Orient. Band X, Heft 2/3 (1964), 189-206; 200.
7. W.M.F. Petrie, The Pyramids and Temples of Gizeh (London, 1883), 83.
8. Bauval, op.cit. (D.E. 16), 22. 9. Petrie, loc.cit.
10. Bauval's date implies a correction for proper motion of 750 years.
11. J.A.R. Legon, D.E. 27 (1993) 35-44, 39.
12. Badawy, op.cit., 190.
13. H. Vyse and J.S. Perring, Appendix to Operations carried on at the Pyramids of Gizeh in 1837 (London, 1842), 67. A current of fresh air flowed down the north entrance passage before the west passage had been opened, thus suggesting that another outlet exists, perhaps on the south side.
14. Legon, op.cit., 42-3. 15. Ibid. 40.
16. W.M.F. Petrie, Medum (London, 1892), 12, Pl. VIII. For the design of the air-shafts, a scale drawing on a 'scribing floor' would have sufficed.
17. Rhind Papyrus, problems 24-34. The term *aha* is here usually translated as 'quantity' or 'heap', but can also denote 'height'.
18. Petrie, op.cit., 220. For an equivalent geometrical construction see J.A.R. Legon, D.E. 12 (1988), 41-48, fig.1.