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A Comparative Study of Lunar Eclipse Calculation Astronomical Algorithm Jean Meeus and Textbook on Spherical Astronomy W.M Smart

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ARTICLE INFO | **ABSTRACT**

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This research presents a comparative analysis of the lunar eclipse calculation method proposed by Jean Meeus in his textbook Astronomical Algorithms and the classical method described by W.M. Smart in his textbook Textbook on Spherical Astronomy. Lunar eclipses are celestial phenomena that can be accurately predicted using certain astronomical techniques. This research aims to evaluate the differences between modern and classical approaches in the calculation process. This research employs empirical data collection and comparison of calculation results on several lunar eclipses to evaluate the accuracy of both methods in predicting the time, duration, and phase of the eclipse. The findings are then compared with the results from NASA. This research is of the library research variety. The sources and types of data employed in this study include astronomical algorithm books and textbooks on spherical astronomy, as well as journal articles that align with the research theme. The data analysis employed by the researchers is a content analysis of the two books, then described with descriptive and comparative techniques. The principal findings of this study indicate that the two books exhibit discrepancies ranging from 3'50' to 19'18'. In comparison, the divergence with NASA results is 0'5.2', 0'10', 3'44.8', and 19'48' more rapid.

ARTICLE INFO | ABSTRAK

Penelitian ini menyajikan analisis komparatif antara metode perhitungan gerhana bulan yang ditawarkan oleh Astronomical Algorithms karya Jean Meeus dan metode klasik dari Textbook on Spherical Astronomy karya W.M. Smart. Gerhana bulan adalah fenomena langit yang dapat diprediksi secara akurat dengan menggunakan teknik-teknik astronomi tertentu, dan penelitian ini berupaya mengevaluasi perbedaan pendekatan modern dan klasik dalam proses perhitungan tersebut. Melalui pengumpulan data empiris dan perbandingan hasil perhitungan pada beberapa gerhana Bulan yang telah terjadi, penelitian ini mengevaluasi keakuratan kedua metode dalam aspek prediksi waktu, durasi dan fase gerhana dengan mengkomparasikannya dengan hasil dari NASA. Penelitian ini masuk dalam kategori penelitian kepustakaan. Sumber dan jenis data yang digunakan yaitu buku Astronomical Algorithm dan buku Textbook on Spherical Astronomy, serta artikel jurnal yang sesuai dengan tema penelitian. Sementara analisis data yang digunakan peneliti adalah analisis isi terhadap kedua buku tersebut, kemudian diuraikan dengan teknik deskriptif dan komparatif. Temuan utama dari penelitian ini menunjukkan bahwa kedua buku tersebut mempunyai perbedaan yang berkisar antara 3′50″ – 19′18″. Sedangkan perbedaannya dengan hasil NASA yaitu 0′5.2″, 0′10″, 3′44.8″, dan 19′48″ lebih cepat.

INTRODUCTION

A lunar eclipse is a phenomenon that can be observed with the naked eye in all locations worldwide.[1] It can be an efficacious pedagogical instrument for introducing the general public to astronomy. Accurate eclipse calculations and predictions facilitate timely public observations and enhance public awareness of astronomy. Lunar eclipse calculations also assist in determining the relative position of the Earth in the solar

[1]Rusydi Sulaiman, "Gerhana Dan Keharusan Kosmologis Manusia: Tinjauan Filsafat Wujud," *Edugama: Jurnal Kependidikan Dan Sosial Keagamaan* 3, no. 2 (2017): 104–26, https://doi.org/10.32923/edugama.v3i2.725. Lihat juga, Muhammad Jayusman, "Hukum Islam Dan Astronomi" X, No. 2, no. 3 (2011).

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system.[2] By understanding the exact position of the Moon and Sun at the time of the eclipse, astronomers can calculate the motion of the Earth and Moon with greater accuracy.[3]

In his book Astronomical Algorithms, the esteemed astronomer Jean Meeus presents a series of algorithms that have become standard in calculating lunar eclipses and other astronomical phenomena.[4] These algorithms are renowned for their precision and extensive mathematical applicability in contemporary astronomy. Conversely, W.M. Smart's Textbook on Spherical Astronomy is regarded as a seminal reference by numerous astronomers for grasping the fundamentals of spherical astronomy, including the calculation of celestial phenomena such as eclipses through the tenets of spherical geometry.[5]

The two books present different algorithms that yield disparate results, particularly in calculating lunar eclipses. That is a crucial area for further investigation, given that the two

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[2]Baiq Anggi Andini, Siti Rabi'atul Adawiyah, and Arino Bemi Sado, "Implementasi Algoritma Jean Meeus Dalam Penentuan Gerhana Bulan Dan Matahari," *AL - AFAQ : Jurnal Ilmu Falak Dan Astronomi* 5, no. 1 (2023): 57–80, https://doi.org/10.20414/afaq.v5i1.7223. Lihat juga, Dewi Gita Rahmayani, "Fenomena Gerhana Bulan Dalam Perspektif Islam," *Jurnal Agama, Sosial, Dan Budaya* 3, no. 2 (2024): 675–82. Dan lihat juga, KKABUS UTSMAN, "Studi Analisis Metode Hisab Gerhana Bulan Dalam Kitab Niẓām Al-Qamarain Fi Hisāb Al-Ijtimā'Wa Al-Hilāl Wa Al," *Eprints.Walisongo.Ac.Id*, 2022. Dan lihat juga, Guillermo Gonzalez, Mutual eclipses in the solar system, *Astronomy & Geophysics*, Volume 50, Issue 2, April 2009, Pages 2.17–2.19, https://doi.org/10.1111/j.1468-4004.2009.50217.x

[3]Ismail Ismail, "Hisab Urfi Gerhana Matahari Dan Gerhana Bulan," *Al-Marshad: Jurnal Astronomi Islam Dan Ilmu-Ilmu Berkaitan* 6, no. 1 (June 1, 2020): 45–59, https://doi.org/10.30596/jam.v6i1.4411.

[4]Dede Muhammad Isnaeni, Fitri Mintarsih, and Feri Fahrianto, "Pencarian Masjid Terdekat," *Studia Informatika: Jurnal Sistem Informasi* 8, no. 1 (2015): 1–10.

[5]Ismail Ismail, "LHOKSEUMAWE SOCIETY RITUALS AT THE SOLAR ECLIPSE (Study of the Solar Eclipse March 9th 2016 and December 26th 2019)," Al-Hilal: Journal of Islamic Astronomy 2, no. 1 (March 8, 2021), https://doi.org/10.21580/al-hilal.2020.2.1.5565.

algorithms employ disparate calculation methodologies. It is crucial to comprehend the methodologies employed by these two sources, namely the Astronomical Algorithms and the Textbook on Spherical Astronomy, in calculating lunar eclipses. By comparing the calculation methods and results of both, this study can provide insight into the relative merits and shortcomings of each approach, as well as its contribution to accuracy and practicality in the context of modern astronomy.

METHOD

This research is a library-based study employing a qualitative descriptive comparative approach. Its objective is to ascertain how the calculation methods utilized in the Astronomical Algorithms book and Textbook on Spherical Astronomy compare when the results are evaluated using parameters based on NASA (National Aeronautics and Space Administration) data. The data sources employed by the researchers are the two books, with supplementary material in the form of scientific journal articles that align with the research theme.

RESULTS AND DISCUSSIONS

Astronomical Algorithms by Jean Meeus

Biografi Jean Meeus

Jean Meeus was born on 12 Desember 1928 M.[6] Jean Meeus is a Belgian meteorologist and astronomer whose research interests include mathematical astronomy, spherical astronomy,

[6]Fiki Nu'afi Qurrota Aini, "Studi Komparatif Sistem Perhitungan Gerhana Matahari Elements of Solar Eclipses Jean Meeus Dan Textbook on Spherical Astronomy W.M. Smart" (UIN Walisongo Semarang, 2019),https://eprints.walisongo.ac.id/9713/1/SKRIPSI LENGKAP.pdf. Lihat juga, Lalu Adam Prayogi, "Studi Komparatif Perhitungan Gerhana Bulan Astronomical Algorithm Jean Meeus Dan Textbook on Spherical Astronomy W.M. Smart," *Skripsi-UIN Mataram* (UIN Mataram, n.d.). dan lihat juga, Indana Zuyyina Illiyyin, "UJI KOMPARASI DATA PERHITUNGAN AWAL WAKTU SALAT ANTARA VERSI TRUNCATED DAN HIGHER ACCURACY DALAM BUKU ASTRONOMICAL ALGORITHMS" (UIN Sunan Ampel Surabaya, 2023).

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and celestial mechanics. He studied mathematics at the University of Leuven, Belgium, and was awarded his license in 1953.[7]

In 1986, Jean Meeus was the recipient of the Amateur Achievement Award from the Pacific Society. Jean Meeus has been a member of the Astronomical Society of France (ASF) since 1948. Meeus has published in excess of one hundred articles. Meeus served as an editor of the company almanac for a period of 25 years. In the course of his studies in astronomy, Jean Meeus made the discovery of the asteroid 2213 Meeus.[8]

Jean Meeus Algorithm Calculaion Model[9]

1. Determining the approximate year of the lunar eclipse
   Approximate year = year + passing month/12 + date/365.

   After getting the results of the year estimate, then determine the value of the Moon's trajectory through the node point (**k**). For the record **k or** the moon's trajectory through the node point is when the moon passes through the node point either up or down from its orbit geocentric latitude of 0.[10] The value of k can be calculated using the following formula:
2. Approximate value of k = (Approximate year– 2000) * 12,3685

   After obtaining the value of k, k is an integer that is added with + 0.5 because the lunar eclipse only occurs during the full moon phase.[11]

   a) New Moon = k=0

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[7]Jauharotul Maknunah Firman, "Rancang Bangun Aplikasi My Eclipse Berbasis Web Metode Jean Meeus" (UIN Walisongo Semarang, 2022).

[8]Aini, "Studi Komparatif Sistem Perhitungan Gerhana Matahari Elements of Solar Eclipses Jean Meeus Dan Textbook on Spherical Astronomy W.M. Smart."

[9]Jean Meeus, *Astronomical Algorithms*, II (Virginia: Willmann-Bell, Inc., 1998).

b) First Quarter Month = 0,25

c) Full Moon = 0,5

If it has been added, the next step is to find the value of T or Julian Day Centuries, which is the time in Julian's centuries since the year (*epoch)* 2000.0, the value of T is obtained by the following formula:

3. $T= k/ 1236.85$

The next step is to calculate the F value or moon latitude argument with the formula:

4. $F = (160{,}7108+390{,}67050274*k–0{,}0016341*T^2) \text{ Mod } 360$

The F value provides information or arguments for the latitude of the Moon in determining the occurrence and non-occurrence of a lunar eclipse. In the conditions for the occurrence of a lunar eclipse, the difference in the value of F is different from the nearest multiple of 180° and less than 13.9° therefore it is certain that an eclipse will occur, but if the difference is greater than 21° then it is certain that there will be no eclipse.

After the value of F is known, the next step is to find the value (E) of the Sun with the formula:

5. $E = 1 – 0{,}002516 \times T – 0{,}0000074 \times T^2$

After the E value is found the next step is to calculate the average Sun anomaly (M) formula:

6. $M = (2{,}5534 + 29{,}1053569 \times K – 0{,}0000218 \times T^2) \text{ Mod } 360$

After obtaining the average anomaly of the Sun, the next step is to calculate the average anomaly of the Moon (M'), namely:

$M' = (201{,}5643 + 385{,}81693528 \times K + 0{,}0107438 \times T^2) \text{ Mod } 360$

After obtaining the results of the average anomaly of the Moon, the next step is to calculate the longitude of the rising point of the Omega Moon (W) formula:

7. $\text{Omega } (\Omega) = (124{,}7746 – 1{,}56375580 \times K + 0{,}0020691 \times T^2) \text{ Mod } 360$

After getting the result of the omega value, the next step is to calculate F1 with the formula:

8. $F1 = F – 0{,}02665 \times \sin \Omega$

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The F1 calculation results are converted into degree units. After getting the F1 value, then calculate the A1 *apparent latitude* formula:

9. A1 = 299,77 – 0,107408 x k – 0,009173 x T^2

   After getting the A1 value, the next step is to calculate the uncorrected JDE value using the formula:

10. Uncorrected JDE = 2451550,09765 + 29,530588853 x K + 0,0001337 x T^2

    After getting the uncorrected JDE value, the next step is to calculate the correction value of the JDE formula:

11. 10000 x JDE correction = -4065 x Sin (M′) + 1727 x E x Sin (M) + 161 x Sin (2xM′) – 97 x Sin (2xF1) + 73 x E x Sin (M′-M) – 50 x E x Sin (M′+M) – 23 x Sin (M′-2xF1) + 21 x E x Sin (2xM) + 12 x Sin (M′ + 2xF1) + 6 x E x Sin (2xM′+M) – 4 x Sin (3xM′) – 3 x E x Sin (M + 2xF1) + 3 x Sin (A1) – 2 x E x Sin (M-2xF1) – 2 x E x Sin (2x M′-M) – 2 x Sin (Ω).

    After calculating the JDE correction, the next step is to calculate the corrected JDE during the maximum eclipse formula:

12. Uncorrected JDE + JDE correction

    After JDE is known, then calculate JD. The process of calculating the JD value is the longest calculation process among other calculation steps. In the Julian calendar, on average one year is defined as 365.25 days, this number is obtained from (365 × 4 + 1)/4 so that in the Julian calendar there is a leap year every 4 years. This Julian calendar was valid until Thursday 4 October 1582. because Pope Gregory changed the Julian calendar by determining that the date 4 October 1582 was Friday 15 October 1582, so that since 15 October 1582 the Gregorian calendar applies.

    The change from the Julian to the Gregorian calendar is caused by the difference between the length of a Julian calendar year and the average length of a tropical year. One Julian calendar is 365.2500 days. The average length of the tropical year is 365.2422 so it has a difference in one year of 0.0078 days or about 11 minutes. The change from the Julian calendar to the Gregorian calendar makes it difficult to compare separate astronomical events over a long period. So to overcome the problems that arise, Julian Day is introduced, which is the number of days that have passed since Monday 1 January 4713 BC at midday at 12:00 UT (Universal Time) or GMT. To calculate JD on the lunar eclipse formula:

13. JD at maximum eclipse = JDE corrected – Delta T
    After JD is known, the next step is to calculate the P value of the formula:
14. 10000 x P = 2070 x E x Sin (M) + 24 x E x Sin (2xM) – 392 x Sin (M′) + 116 x Sin (2xM′) – 73 x E x Sin (M′ + M) + 67 x E x Sin (M′-M) + 118 x Sin (2x F1).
    After the P value is known, the next step is to calculate Q with the formula:
15. 10000 x Q = 52207 – 48 x E x cos (M) + 20 x E x cos (2xM) – 3299 x cos (M′) – 60 x E x cos (M′ + M) + 41 x E x cos (M′ – M)
    After knowing the value of Q The next step is to calculate the value of W formula:
16. W = Abs (Cos(F1))
    After knowing the value of W the next step is to calculate the value of γ formula:
17. γ = (P x cos (F1) + Q x Sin (F1)) x (1 – 0,0048 x W)
    After knowing the value of γ, the next step is to calculate the value of U formula:
18. 10000 x U = 59 + 46 x E x cos (M) – 182 x cos (M′) + 4 x Cos (2x M′) – 5 x E x Cos (M+ M′)
    After knowing the U value, the next step is to calculate the penumbra radius formula:
19. Radius of the penumbra = 1,2848 + U
20. Radius of the umbra = 0,7403 – U
21. Magnitude of penumbral eclipse = (1,5573 – U – Abs (Gamma)) / 0,545

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Next, calculate the magnitude of the umbra eclipse formula:

22. Magnitude of umbra eclipse = (1,5573 – U – Abs (Gamma)) / 0,545
23. Pu = 1,0128 – U
24. T1 = 0,4678 – U
25. H = 1,5573 + U
26. n = 0,5458 + 0,0400 x cos (M′)
27. Semi duration penumbra = (60/n) x SQRT ($H^2 - \gamma^2$)
28. Semi duration phase parsial umbra = (60/n) x SQRT ($Pu^2 - \gamma^2$)
29. Semi duration phase total umbra = (60/n) x SQRT ($T1^2 - \gamma^2$)
30. Beginning of penumbral phase P1 = jd time – 176,66 minute

    Determining the beginning of the umbra phase U1 formula:
31. U1= jd time – 105,8 minute

    Determining the initial value of the total phase U2 formula:
32. U2 = jd time – 24,83 minute

    Determining the maximum eclipse time formula:
33. Maximum eclipse = centre of the eclipse

    Determine the total phase end time U3 formula:
34. U3 = maximum eclipse time + 24,83 minute

    Determining the end of umbra phase U4 formula:
35. U4 = maximum eclipse time + 105,8 minute

    The last step is to determine the end of the penumbral phase P2 formula:

    P2 = maximum eclipse time + 176,66 minute

Textbook on Spherical Astronomy by W.M. Smart

Biography of William Marshil Smart

William Marshall Smart was born on 9 March 1889, in Doune, Scotland, and died on 17 September 1975.[12] Smart was a Scottish astronomer since the 20th century, he also had an MA from the University of Glasgow in 1910 in maths and natural philosophy. After JDE is known, then calculate JD. The process of calculating the JD value is the longest calculation process among other calculation steps. In the Julian calendar, on average one year is defined as 365.25 days, this number is obtained from (365 × 4 + 1)/4 so that in the Julian calendar there is a leap year every 4 years.

This Julian calendar was valid until Thursday 4 October 1582. because Pope Gregory changed the Julian calendar by determining that the date 4 October 1582 was Friday 15 October 1582, so that since 15 October 1582 the Gregorian calendar applies.[13] He proceeded to attain a first in triple mathematics at Trinity College, Cambridge and subsequently received the Tyson Medal for Astronomy.

Smart served in the Royal Navy during the First World War, where he was a navigation instructor. He subsequently returned to Cambridge in 1919 as the John Couch Adams lecturer in mathematics and astronomy. Together with Commander FN Shearme, he authored the Naval Navigation Manual (1922).[14] Smart has published four volumes of books on sea and air navigation that have subsequently been adopted as standard textbooks for the armed forces. He authored over twenty academic papers throughout his career and was acknowledged as a prominent figure in his field. He served as President of the Royal Astronomical Society from 1949 to 1951.

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[12]https://en.wikipedia.org/wiki/William_Marshall_Smart. Diakses pada tanggal 31 Oktober 2024, pukul 21.14 WIB.

[13]https://en.wikipedia.org/wiki/William_Marshall_Smart.

[14]https://en.wikipedia.org/wiki/William_Marshall_Smart..

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W.M. Smart Algoithm Calculation Model[15]

1. View the date of the lunar eclipse through NASA data
2. Finding the largest FIB on the lunar eclipse date in the Ephemeris data
3. Finding the Moon Declination in the Ephemeris data at the greatest FIB hour and 1 hour after = δ_1 dan $\delta_{1'}$
4. Finding the Sun's Declination in the Ephemeris data at the greatest FIB hour and 1 hour after it = δ_0 dan $\delta_{0'}$
5. Finding the Moon's Rectangular Asensio in the Ephemeris data at the hour of greatest FIB and 1 hour after it = α_1 dan $\alpha_{1'}$
6. Finding the Sun's Rectangular Asensio in the Ephemeris data at the hour of greatest FIB and 1 hour later = α_0 dan $\alpha_{0'}$
7. Calculating the Sun's Rectangular Asensio at the largest FIB Hour = α_0 + 12 h[16]
8. Calculating the Sun's Rectangular Asensio at the greatest FIB Hour 1 hour later = $\alpha_{0'}$ + 12 h
9. Calculating the value of $x = (\alpha_1 - \alpha_0) \cos \delta_1$
10. Calculating the value of $x' = (\alpha_1' - \alpha_1') \cos \delta_1'$
11. Calculating the value of $y = \delta_1 - \delta_0$
12. Calculating the value of $y' = \delta_{1'} - \delta_{0'}$
13. Calculating the value of $x_0 = (x - x')$
14. Calculating the value of $y_0 = (y - y')$
15. Calculating the value of M = tan M = x_0 / y_0
16. Calculating the value of m = $x_0 / \sin M$
17. Calculating the value of N = tan N = $x_{'} / y_{'}$
18. Calculating the value of n = $x_{'} / \sin N$
19. Calculating the value of t′ = -m/n*cos (M-N)[17]

[15]William Marshall Smart, "*Textbook on Spherical Astronomy*". (Great Britain: University Press, Cambridge, 1977), hlm 384.
[16]William Marshall Smart, "*Textbook on Spherical Astronomy*". (Great Britain: University Press, Cambridge, 1977), hlm 384.
[17]W.M. Smart, hlm 385.

20. Calculating the value of $\eta^2 = m^2 + 2*m*n*t*\cos(M-N) + n^{2}*t^{2}$[18]
21. Calculating the value of $\sin \psi = m*\sin (M-N)/\eta^2$ dan ψ value = $\sin^{-1} \psi$
22. Logicising T0 (the largest FIB in the Ephemeris data). T0 in this calculation can be taken with the logic of 1-T0, T0, 1+T0. Note T0 is the largest FIB hour on the date of the lunar eclipse. Calculating the value of $T0 = -m/n*\cos (M-N) + \eta^2/n*\cos \psi$ dan nilai $T02 = -m/n*\cos (M-N) - \eta^2/n*\cos \psi$ in calculating T0 and T02, positive values should be taken.

Calculating the value of $\eta = 51/50*(P+P_1-S)+S_1$[19]

P is the Equatorial Horizontal Parallax of the Sun.[20]
P_1 is the equatorial horizontal parallax of the Moon.
S is the Semi Diameter of the Sun.
S_1 is the Semi Diameter of the Moon.

23. Calculating the beginning of the eclipse = eclipse centre time - η
24. Calculating the centre of the eclipse = T0 + t′
25. Calculating the end of the eclipse = eclipse centre time + η

Accuracy of Lunar Eclipse Calculations of Jean Meeus and W.M. Smart

Following an analysis of the discrepancies between lunar eclipse calculation systems, researchers are now undertaking precision trials utilizing both the Astronomical Algorithm lunar eclipse calculation system and the Textbook on Spherical Astronomy. Given the Astronomical Algorithm system's reputation for accuracy, these trials are of paramount importance.[21]

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[18]W.M. Smart, hlm 384.

[19]W.M. Smart, hlm 385.

[20]W.M. Smart, hlm 379.

[21]Fitri Lindayunita, "Perbedaan Paradigma Kosmologi Antara Stephen Hawking Dan Al-Farabi," *Astroislamica: Journal of Islamic Astronomy* 4, no. 1 (June 1, 2025): 105–21, https://doi.org/10.47766/astroislamica.v4i1.4820.

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A study was conducted to evaluate the precision of the lunar eclipse calculation system. To this end, two distinct calculation systems were subjected to an accuracy test: The Astronomical Algorithm and the Textbook on Spherical Astronomy. The research was conducted on two occasions: on 26 May 2021 and on 8 November 2022. The researchers have calculated the accuracy of the calculations for the lunar eclipse made by the Astronomical Algorithm and the Textbook on Spherical Astronomy. The following section presents the results of the calculations performed by the two calculation systems.

1. Lunar Eclipse *Astronomical Algorithm* and *Textbook on Spherical Astronomy*

a. Lunar eclipse calculation *Astronomical Algorithm* on 08 November 2022

Table 1. Jean Meeus Lunar Eclipse Calculation Wednesday, 08 November 2022

Not.	*Description*	*Formula*	*Result*
1.	Calculating Approximate year	year + month that passed ÷ 12 + date ÷ 365	2022,85525114155
2.	Approximate value of K	(Approximate year – 2000,0185) * 12,3683	282,45178914406
3.	Determining the correct K value. For a lunar eclipse it is an integer + 0.5. Taken from the nearest value		282,5
4.	Determining T Value	T = K ÷ 1236,85 T = 282,5 ÷ 1236,85	0,22840279742895
5.	Determining F Value (Moon latitude argument)	F = (160,7108 + 390,67050274* K – 0,0016341*T^2) Mod 360	5,1277

6.	Determine whether there is a lunar eclipse from the F value above. The requirement for an eclipse F with a multiple of 180° must be less than 13.9°.		Eclipse occurs
7.	Calculating value E	E = 1 – 0,002516 x T – 0,0000074 x T^2	0,999424924952519668
8.	Calculating average Sun anomaly (M)	M = (2,5534 + 29,1053569 x K – 0,0000218 x T^2) Mod 360	5,32005439804067
9.	Calculating average Moon Anomaly (M)	M' = (201,5643 + 385,81693528 x K + 0,0107438 x T^2) Mod 360	2,004494537936940
10.	Calculating the longitude of the rising point of the Omega Moon (W)	Ω = (124,7746 – 1,56375580 x K + 0,0020691 x T^2) Mod 360	0,75073059143304
11.	Calculating F1	F1 = F – 0,02665 x Sin Ω	0,08917862592484
12.	Calculating A1	A1 = 299,77 – 0,107408 x k – 0,009173 x T^2	5,76154621282443
13.	Calculating uncorrected JDE of the Moon	Uncorrected JDE = 2451550,09765 + 29,530588853 x K + 0,0001337 x T^2	2459892,48900795

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14.	Calculating JDE correction	10000 x JDE correction = -4065 x Sin (M′) + 1727 x E x Sin (M) + 161 x Sin (2xM′) – 97 x Sin (2xF1) + 73 x E x Sin (M′-M) – 50 x E x Sin (M′+M) – 23 x Sin (M′-2xF1) + 21 x E x Sin (2xM) + 12 x Sin (M′ + 2xF1) + 6 x E x Sin (2xM′+M) – 4 x Sin (3xM′) – 3 x E x Sin (M + 2xF1) + 3 x Sin (A1) – 2 x E x Sin (M-2xF1) – 2 x E x Sin (2x M′-M) – 2 x Sin (Ω).	-0,53036337973510
15.	Calculating the corrected JDE at the time of maximum eclipse	Uncorrected JDE + JDE Correction	2459891,95864457
16.	Calculating the JDE at maximum eclipse	JDE corrected – Delta T.	2459891,95780660
17.	Calculating P	10000 x P = 2070 x E x Sin (M) + 24 x E x Sin (2xM) – 392 x Sin (M′) + 116 x Sin (2xM′) – 73 x E x Sin (M′ + M) + 67 x E x Sin (M′-M) + 118 x Sin (2x F1).	-0,219556398
18.	Calculating Q	10000 x Q = 52207 – 48 x E x cos (M) + 20	5,348834748

		x E x cos (2xM) – 3299 x cos (M′) – 60 x E x cos (M′ + M) + 41 x E x cos (M′ – M)	
19.	Calculating value W	ABS (cos (F1)).	0,996026221
20.	Calculating value γ	(P x cos (F1) + Q x Sin (F1)) x (1 – 0,0048 x W)	0,256453826
21.	Calculating U	10000 x U = 59 + 46 x E x cos (M) – 182 x cos (M′) + 4 x Cos (2x M′) – 5 x E x Cos (M+ M′)	0,015661945
22.	Calculating the radius of the Penumbra	1,2848 + U	1,300461945
23.	Calculating the radius of the Umbra	0,7403 – U	0,724638055
24.	Calculating the Magnitude of a Penumbral eclipse	(1,5573 – U – ABS (γ)) / 0,545	2,3581362
25.	Calculating the Magnitude of a Umbra eclipse	(1,0128 – U – ABS (γ)) / 0,545	1,3590553631
26.	Calculating Pu	1,0128 – U	0,997138055
27.	Calculating T1	0,4678 – U	0,452138055
28.	Calculating H	1,5573 + U	1,572961945
29.	Calculating n	0,5458 + 0,0400 x cos (M′)	0,52899082

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30.	Calculating the semi-duration of the penumbral phase	(60/n) x SQRT (H^2 – $Gamma^2$)	176,0236794
31.	Calculating the semi-duration of the umbra partial phase	(60/n) x SQRT (Pu^2 – $Gamma^2$)	109,2943594
32.	Calculating the semi-duration of the total umbra phase	(60/n) x SQRT ($T1^2$ – $Gamma^2$)	42,23564328
33.	Calculating the penumbral phase (P1)	centre of eclipse - semi-duration of penumbral phase	8: 03: 13 UT
34.	Beginning of umbra phase (U1)	centre of eclipse - semi-duration of penumbral partial phase	9: 09: 57 UT
35.	Beginning of total phase (U2)	centre of eclipse - semi duration of total umbra phase	10: 17: 00 UT
36.	Maximum eclipse	centre of the eclipse	10: 59: 14 UT
37.	End of total phase (U3)	centre of eclipse + semi duration of phase Total umbra	11: 41: 29 UT
38.	End of umbra phase (U4)	Centre of eclipse + semi-duration of umbra partial phase.	12: 48: 32 UT
39.	End of penumbral phase (P2)	centre of eclipse + semi duration of penumbral phase	13: 55:16 UT

CONCLUSION

Beginning of Penumbra	**8: 03: 13 UT**	**16: 03: 13 WITA**
Beginning of Umbra	**9: 09: 57 UT**	**17: 09: 57 WITA**
Beginning Total	**10: 17: 00 UT**	**18: 17: 00 WITA**
Middle of the eclipse	**10: 59: 14 UT**	**18: 59: 14 WITA**
End of Total	**11: 41: 29 UT**	**19: 41: 29 WITA**
End of Umbra	**12: 48: 32 UT**	**20: 48: 32 WITA**
End of Penumbra	**13: 55:16 UT**	**21: 55:16 WITA**

b. Lunar Eclipse Calculation *Textbook on Spherical Astronomy* on 08 November 2022

In calculating the lunar eclipse, Ephemeris data is needed and the Ephemeris data is in the appendix.

Table 2. W. M Smart Lunar Eclipse Calculation 08 November 2022

Not.	*Description*	*Formula*	*Result*
1.	Search for the time the eclipse occurred in NASA data		8 November 2022
2.	Finding the largest FIB in the Ephemeris data		11 GMT
3.	Finding the Moon Declination in the Ephemeris data at the largest FIB hour and 1 hour after it		δ_1= 16°51′04″ δ_1'= 17°03′03″
4.	Find the Sun's Declination in the Ephemeris data 1 hour later		δ_0 = -16°37′47″ = 16°37′47″ δ_0' = -16°38′30″ =16°38′30″
5.	Finding the Moon's Rectangular Asensio in the Ephemeris data at the hour of greatest FIB and 1 hour after it		α_1 = 43°26′33′′ α_1' = 43°57′35′′
6.	Finding the Moon's Rectangular Asensio		α_0 = 223°32′46′′ α_0' = 223°35′17′′

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	in the Ephemeris data at the hour of greatest FIB and 1 hour after it		
7.	Calculating the Sun's Rectangular Asensio at the largest FIB Hour	FIB terbesar $= \alpha_0 + 12$ h	= 223°32′46′′ + 180° = 403°32′46″ - 360° = 43°32′46″
8.	Calculating the Sun's Rectangular Asensio at the greatest FIB Hour 1 hour later	FIB terbesar 1 jam setelahnya $= \alpha_{0'} + 12$ h	= 223°35′17″ +180° = 403°35′17″ - 360° = 43°35′17″
9.	Calculating the value of x	$x = (\alpha_1 - \alpha_0) \cos \delta_1$	= (43°26′33′′-43°32′46″) *cos 16°51′04″ x = -0°5′56,98″
10.	Calculating the value of x′	$x' = (\alpha_1' - \alpha_1') \cos \delta_1'$	= (43°57′35′′-43°35′17″) * cos 43°35′17″ x′ = 0°21′19,08″
11.	Calculating the value of y	$y = \delta_1 - \delta_0$	= 16°51′04′′-16°37′47′′ y = 0°13′17″
12.	Calculating the value of y′	$y' = \delta_{1'} - \delta_{0'}$	= 17°03′03′′-16°38′30′′ y' = 0°24′33″
13.	Calculating the value of x_0	$x_0 = (x - x')$	= -0°5′56,98″-0°21′19,19″ x_0 = 0°27′16,17″
14.	Calculating the value of y_0	$y_0 = (y - y')$	= 0°13′17″-0°24′33″ y_0 = -0°11′16″
15.	Calculating the value of M	M = tan M = x_0/y_0	Tan M = -0°27′16,17″/ -0°11′16″ M = 67°33′5,65″
16.	Calculating the value of m	m = x_0/sin M	m = -0°27′16,17″/ sin 67°33′5,65″ m = - 0°29′30,32″
17.	Calculating the value of N	N = tan N = $x_{'}/y_{'}$	Tan N = 0°21′19,19″/ 0°24′33″ N = 40°58′18,55″

18.	Calculating the value of n	n = x′/sin N	n = 0°21′19,19″/ sin40°58′18,55″ n = 0°32′30,91″
19.	Calculating the value of t	t′ = -m/n*cos (M-N)	t′ = -(0°29′30,32″ /0°32′30,91)*cos(67°33′5,56″-40°58′18,55) t′= 0°48′42″
20.	Calculating the value of η^2	η^2 = m^2 + 2*m*n*t*cos (M-N) + n^2*t^2	η^2 = 0°29′30,32″^{2} + 2 * -0°29′30,32″*0°32′30,9″ * 0°48′42″ * cos(67°33′5,65″-40°58′18,5″) + 0°32′30,91″^{2} * 0°48′42″^{2} η^2 = 4°59′3,38″
21.	Calculating the value of sin ψ	sin ψ = m*sin (M-N)/η	sin ψ = - 0°29′30,32″ *sin (67°33′5,65″-40°58′18,55″)/ 4°59′3,38″ sin ψ = -0°2′38,92″
22.	Calculating the value of ψ	ψ = $\sin^{-1}$ ψ	ψ = $\sin^{-1}$ -0°2′38,92″ ψ = -2°31′48,6″
23.	Calculating the value of T0	T0=-m/n*cos (M-N)+ η^2/n*cos ψ	T0 = -(- 0°29′30,32″/ 0°32′30,91″)* cos(67°33′5,65″-40°58′18,55″) + 4°59′3,38″/ 0°32′30,91″* cos -2°31′48,6″ T0 = 10°6′46,44″
24.	Calculating the value of T02	T02 = -m/n*cos (M-N) - η^2/n*cos ψ	T02 = -(-0°29′30,32″/ 0°32′30,91″)* cos(67°33′5,65″-40°58′18,55″) - 4°59′3,38″/ 0°32′30,91″* cos -2°31′48,6″ T02 = -8°15′50,55″

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25.	Calculating the value of η	η = 51/50*(P+P_1 -S)+S_1	η = 51/50*(0°1′0″+ 0°56′08″- 0°16′08,55″) + 0°15′17,75″ η = 1°44′52,61″
26.	Calculating the beginning of the eclipse	eclipse start = eclipse centre time - η	Ag = 10°55′28″- 1°44′52,61″ Ag = 9°10′35,39″
27.	Calculating the centre of the eclipse	centre of the eclipse = T0 + t′	T0 = 10°6′46,44″ + 0°48′42″ T0 = 10°55′28′′
28.	Calculating the end of the eclipse	end of eclipse = middle time of eclipse + η	Ag = 10°55′28′′+ 1°44′52,61″ = 12°40′20,61′′
CONCLUSION			
Beginning of eclipse		**9°10′35,39″ UT**	**17°10′35,39′′ WITA**
Centre of eclipse		**10°55′28″ UT**	**18°55′28″ WITA**
End of eclipse		**12°40′20,61′′ UT**	**20°40′20,61″ WITA**

Following the aforementioned series of steps, the calculation of the lunar eclipse in the preceding or subsequent year can also be determined. However, the distinguishing factor is the ephemeris data employed. The ephemeris data can be found in the Indonesian Ministry of Religious Affairs' annual publication, the Ephemeris Hisab Rukyat. To obtain the data required for the calculation, it is necessary to pay attention to the hour, date, and year in question. The following section presents the results of the calculation of the lunar eclipse using the methods outlined in the Astronomical Algorithm and Textbook on Spherical Astronomy, with a comparison to the NASA lunar eclipse schedule.

Astronomical Algorithm	Textbook on Spherical Astronomy	NASA
08 November 2022		
18° 59′ 14″ WITA	18° 55′ 24″ WITA	18° 59′ 08.8″ WITA
26 Mei 2021		
19° 18′ 30″ WITA	18° 58′ 52″ WITA	19° 18′ 40″ WITA

The data presented above allows us to conclude that there is a mere 5.2-second discrepancy between the times of the lunar eclipse as calculated by the Astronomical Algorithm book method and that provided by NASA on 8 November 2022. In contrast, the discrepancy between the times calculated by the method described in the textbook on spherical astronomy and those provided by NASA is 3 minutes 44.8 seconds. On 26 May 2021, the Astronomical Algorithm in conjunction with NASA yielded a discrepancy of merely 10 seconds, whereas the NASA textbook on spherical astronomy combination exhibited a divergence of 19 minutes and 48 seconds.

CONCLUSION

The accuracy of the lunar eclipse calculation system on the Astronomical Algorithm can be categorized as accurate, employing modern methods. The textbook on Spherical Astronomy, which includes the classical method, is not an accurate source of information regarding calculations. The discrepancy between the astronomical algorithm and NASA is merely 0–10 seconds, whereas the textbook on spherical astronomy can reach almost 20 minutes.

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