Online ISSN: 2249-4596
Print ISSN: 0975-5861
DOI: 10.17406/GJRE

Global Journal
of Researches in Engineering: D

Aerospace Sciences
Aeronautics & Astronautics

Internal Ballistics Simulation

Maneuvering Aerodynamic Target

Highlights

Synthesis and Research of Filter

Influence of UAV Wingtip Connection

Discovering Thoughts, Inventing Future

VOLUME 23 ISSUE 1 VERSION 1.0

Global Journal of Researches in Engineering: D
Aerospace Engineering

Global Journal of Researches in Engineering: D
Aerospace Engineering

Volume 23 Issue 1 (Ver. 1.0)

Open Association of Research Society

Incorporation No.: 0423089
License No.: 42125/022010/1186
Registration No.: 430374
Import-Export Code: 1109007027
Employer Identification Number (EIN):
USA Tax ID: 98-0673427

Global Journals Inc.

*(A Delaware USA Incorporation with "Good Standing"; **Reg. Number: 0423089**)*

Sponsors: *Open Association of Research Society*
Open Scientific Standards

Publisher's Headquarters office

Global Journals® Headquarters
945th Concord Streets,
Framingham Massachusetts Pin: 01701,
United States of America
USA Toll Free: +001-888-839-7392
USA Toll Free Fax: +001-888-839-7392

Offset Typesetting

Global Journals Incorporated
2nd, Lansdowne, Lansdowne Rd., Croydon-Surrey,
Pin: CR9 2ER, United Kingdom

Packaging & Continental Dispatching

Global Journals Pvt Ltd
E-3130 Sudama Nagar, Near Gopur Square,
Indore, M.P., Pin:452009, India

Find a correspondence nodal officer near you

To find nodal officer of your country, please email us at *local@globaljournals.org*

eContacts

Press Inquiries: *press@globaljournals.org*
Investor Inquiries: *investors@globaljournals.org*
Technical Support: *technology@globaljournals.org*
Media & Releases: *media@globaljournals.org*

Pricing (Excluding Air Parcel Charges):

Yearly Subscription (Personal & Institutional)
250 USD (B/W) & 350 USD (Color)

Editorial Board

Global Journal of Research in Engineering

Dr. Omid Gohardani

Ph.D. Senior Aerospace/Mechanical/ Aeronautical, Engineering professional M.Sc. Mechanical Engineering, M.Sc. Aeronautical Engineering B.Sc. Vehicle Engineering Orange County, California, US

Dr. Paolo Veronesi

Ph.D., Materials Engineering, Institute of Electronics, Italy President of the master Degree in Materials Engineering Dept. of Engineering, Italy

Contents of the Issue

Global Journal of Researches in Engineering: D
Aerospace Science
Volume 23 Issue 1 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Study on the Influence of UAV Wingtip Connection on Ceiling and Endurance

By Wei Zhou, Peiyang Ma, Qiuyan Wang, Xueqian Shi & Kaixuan Liu
Rocket Force University of Engineering

Abstract- The cluster UAVs have developed rapidly in recent years with the advantages of low cost, expandability and high reliability. However, due to their small size, they have the shortages of range and flight time. Wingtip connection technology, as an important way to increase the range and flight time of fixed-wing cluster UAVs, has also developed rapidly in recent years. From the theoretical analysis, it is concluded that the wingtip connection can effectively improve the aerodynamic characteristics of fixed-wing UAVs, and the conclusions are validated by vortex lattice method simulation. Based on this, the influence of the number of units on the flight performance of the combination is analysed theoretically. As the number of units increases, the combination can have higher ceiling, larger range and longer flight time.

GJRE-D Classification: FOR Code: 090199

STUDYONTHEINFLUENCEOFUAVWINGTIPCONNECTIONONCEILINGANDENDURANCE

Strictly as per the compliance and regulations of:

Study on the Influence of UAV Wingtip Connection on Ceiling and Endurance

Wei Zhou [α], Peiyang Ma [σ], Qiuyan Wang [ρ], Xueqian Shi [Ѡ] & Kaixuan Liu [¥]

Abstract- The cluster UAVs have developed rapidly in recent years with the advantages of low cost, expandability and high reliability. However, due to their small size, they have the shortages of range and flight time. Wingtip connection technology, as an important way to increase the range and flight time of fixed-wing cluster UAVs, has also developed rapidly in recent years. From the theoretical analysis, it is concluded that the wingtip connection can effectively improve the aerodynamic characteristics of fixed-wing UAVs, and the conclusions are validated by vortex lattice method simulation. Based on this, the influence of the number of units on the flight performance of the combination is analysed theoretically. As the number of units increases, the combination can have higher ceiling, larger range and longer flight time.

I. Introduction

With the increasingly complex battlefield environment, the war has put forward higher requirements for the mission capability and viability of UAVs. The cost of large strategic deterrence UAVs continues to rise, and the cluster UAVs have gradually become a new focus [1]. However, due to the cost and volume constraints, cluster UAVs are inherently short of range and endurance. At present, there are three common methods to improve the range and endurance of the aircraft: First, the aerial refuelling technology is adopted, but for a large number of cluster UAVs, the efficiency of aerial refuelling cannot meet the actual needs. The second is to use a large aspect ratio design combined with solar power module, but for clustered UAVs that need high flexibility and mobility, the aspect ratio will be greatly limited, while the small aspect ratio combined with solar power module will have very low income. Third, like the "Gremlins" in the United States, large transport planes are used for long-distance delivery, but this only solves the problem of long distance, not the endurance time.

In recent years, with the rise of clustered UAVs, a technology that once appeared has been re-valued, namely wingtip connection technology. Scientists hope that the fixed-wing cluster UAVs can form a combination with a large aspect ratio through wingtip connection. At this time, if the UAVs combined with solar technology, the range and endurance time can be greatly extended [2].

Wingtip connection was first proposed by Richard Vogt, a German scientist who immigrated to the United States after World War II. Based on this concept, the United States carried out “MX-1018” (Tip-Tow) and “Tom Tom” projects. However, due to the aerodynamic interference at the wingtip, this research has caused great potential safety hazards and even casualties. In addition, the impact of the gradual maturity of aerial refuelling technology at that time temporarily caused the flight test of wingtip connection stop [3].

Since the 21st century, scientists in the United States, Germany and China have seen the great value of wingtip connection, see Figure 1, for it can improve the ceiling and endurance of cluster UAVs, and gradually resumed and accelerated the study on wingtip connection. Through computational fluid dynamics analysis and wind tunnel test, American scientists analysed and studied aerodynamics and aerodynamic control in the process of wingtip connection [4-7], and verified the flight control system through flight test [8-10]; German scientists mainly explored and practiced the wingtip connection technology in engineering [11], and focused on designing the control system of the combination [12]; Since 2018, China has started the exploration and study of relevant technologies, demonstrated that wingtip connection can improve range and endurance [13, 14], and conducted relevant flight tests [15, 16].

Author α σ ρ Ѡ ¥: *Rocket Force University of Engineering, Xi’an, China.*
e-mail: mpy314159@126.com

Figure 1: Cluster UAVs with wingtip connection

In this paper, through the study on the aerodynamic theory of the UAV combination, simulation and example verification are carried out on the improvement of the ceiling and endurance of the wingtip connection, so as to verify that the clustered UAVs can improve the ceiling and endurance by wingtip connection.

II. Basic Theoretical Research on Flight Performance of Wingtip Connection

Taking the conventional aircraft with a wing, without offset, dihedral and twist, as an example, the aerodynamic performance of the combination formed by the wingtip connection of the flying units with identical *n* frames is analysed theoretically.

a) *Effect of Wingtip Connection on Lift-drag Ratio*

Lift-drag ratio is the most intuitive embodiment of aircraft aerodynamic performance. The larger the lift-drag ratio, the better the aerodynamic performance. In this section, it is assumed that the external environment before and after wingtip connection is unchanged, and the flight altitude and speed of the aircraft are unchanged. When the flight state is approximately at the minimum resistance, the endurance can reach the maximum. This is an ideal state, which can predict the trend and simplify the formula. For this state, there is always a waste resistance coefficient, C_{D0n}, equal to the induced resistance coefficient, C_{Din}, because the induced resistance is inversely proportional to the square of the velocity, and the waste resistance is proportional to the square of the velocity. When the two are equal, the total resistance is the smallest, see Figure 2, that is

$$C_{Dn} = C_{Din} + C_{D0n} = 2C_{D0n} \tag{1}$$

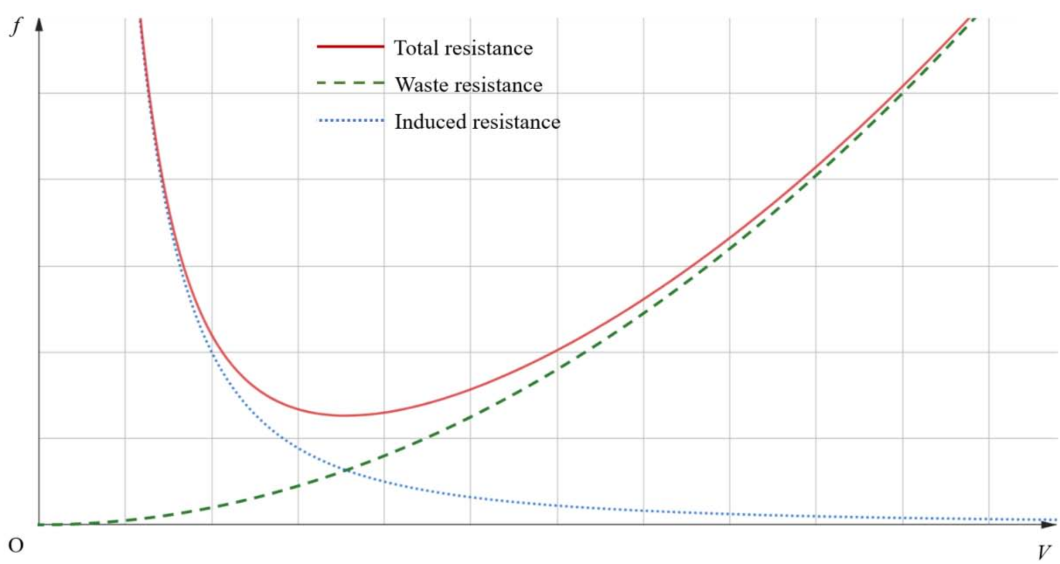


Figure 2: Relationship between resistance and speed

Of which,

$$\begin{cases} C_{D0n} = \dfrac{C_{Ln}^2}{\pi A_n e_n} \\ A_n = nA \end{cases} \tag{2}$$

Where, C_D is the resistance coefficient, C_L is the lift coefficient, and A is the aspect ratio, e is Oswald efficiency factor, and the lower corner mark n represents the number of same flight units formed the combination.

The lift-drag ratio, K, can be derived from equations (1) and (2).

$$K_n = \frac{C_{Ln}}{C_{Dn}} = \sqrt{\frac{\pi A_n e_n}{4C_{D0n}}} = \sqrt{\frac{\pi A}{4C_{D0n}}} \cdot \sqrt{ne_n} \tag{3}$$

Under the assumptions in this section, the parasitic resistance coefficient of the combination is equal to the coefficient of the flight unit, which is a constant, that is $C_{D0n} = C_{D0}\sqrt{\frac{\pi A}{4C_{D0n}}}$.

$$K_n \propto \sqrt{ne_n} \tag{4}$$

That is, the lift-drag ratio of the assembly K_n is proportional to $\sqrt{ne_n}$. Here, the Oswald efficiency factor can be calculated according to the formula mentioned in literature [2], that is

$$e_n = \frac{1}{\pi nAkC_{d0} + 1/(\mu s)} \tag{5}$$

Where, according to the Oswald efficiency coefficient of the high aspect ratio wing, k is assumed to be 0.18[17], C_{d0} is the resistance coefficient of the airfoil. μ is the theoretical Oswald coefficient without considering the influence of the fuselage, s indicating the influence of the fuselage on the induced resistance, which is a function of the fuselage diameter d and the wingspan b.

$$s = 1 - 2\left(\frac{d}{b}\right)^2 \tag{6}$$

For the specified flight unit, in equation (5), all are constants except e_n and n, so it is advisable to set

$$\begin{cases} k_1 = \pi AkC_{d0} \\ k_2 = 1/(\mu s) \end{cases} \tag{7}$$

Then equation (5) can be reduced to

$$e_n = \frac{1}{k_1 n + k_2} \tag{8}$$

It can be seen that Oswald efficiency factor decreases with n increasing.

b) Effect of Wingtip Connection on Cruise Speed

This section assumes that the maximum lift-drag ratio point of the flight unit is taken at 0°, so that the cruise speed of the flight unit is the speed of horizontal flight at 0° angle of attack. It is assumed that the force balance of flight units before and after the wingtip connection is always satisfied, and the flight altitude remains unchanged.

Define that in the two-dimensional plane, the horizontal flight direction of the aircraft is the x-axis positive direction, and the y-axis is perpendicular to the x-axis and upward. Carry out force analysis on the X and Y directions of the aircraft respectively, and then equation (9) is on X axis, equation (10) is on Y axis.

$$F_n = D_n = \frac{1}{2}\rho_n V_n^2 C_{Dn} S_n \tag{9}$$

$$G_n = L_n = \frac{1}{2}\rho_n V_n^2 C_{Ln} S_n \tag{10}$$

It can be seen from equation (9) and (10),

$$F_n = G_n / K_n \tag{11}$$

That is, when the maximum lift-drag ratio is reached, the cruising pull is the smallest, so that the endurance time is the longest.

The lift coefficient calculation formula given by reference [15] under the constant speed assumption.

$$C_{Ln} \approx \left(\frac{1}{2}\rho_n V_n^2\right)^{-1} \frac{nL_i - 2\Delta L}{nS} = \left(\frac{1}{2}\rho_n V_n^2\right)^{-1} \left(\frac{L_i}{S} - 2\frac{\Delta L}{nS}\right) \tag{12}$$

It can be seen that the lift coefficient increases with the increasing of n. Where L_i is the ideal lift of a single wing calculated according to the two-dimensional infinite length model, and ΔL is the lift difference for one side of a single wing. Under the assumption of this section, when G_n unchanged, V_n gradually decreases with the increase of C_{Ln}, and equation (10) can be reduced to equation (13).

$$V_n \propto \sqrt{\frac{1}{C_{Ln}}} \tag{13}$$

That is, the cruising speed of the combination is inversely proportional to $\sqrt{C_{Ln}}$.

III. Simulation Study on Flight Performance of Wingtip Connection

The vortex lattice method is used to simulate the aerodynamic performance of the wingtip connection. Under the constant lift mode, the simplified full USA-35b airfoil model of a rectangular wing with 3 m wingspan and 0.4 m chord length is calculated, as shown in Figure 3, assuming that the wingtip is rigidly connected and there is no gap. The mass of the flight unit is 60 kg, when the angle of attack is $\alpha = 0°$ and the torque coefficient $C_m = 0$ at approximately the maximum lift-drag ratio.

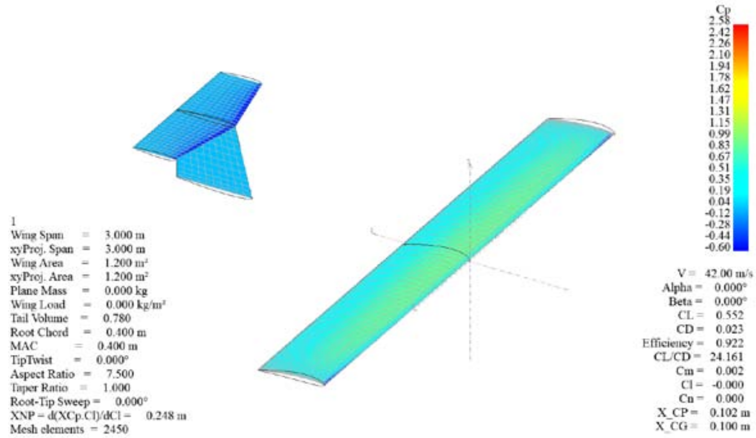
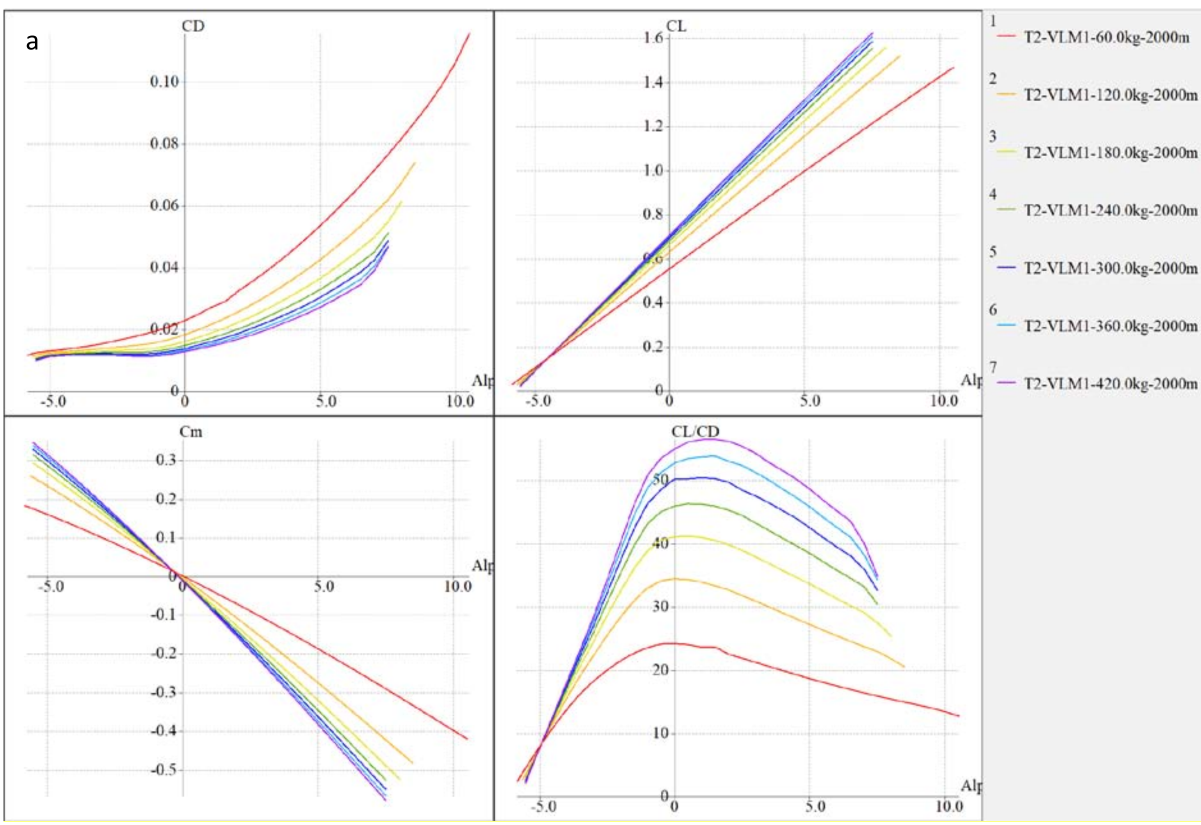


Figure 3: Simulation Model of flight unit

The approximate equivalent method of direct size increase is used in the calculation of the combination, which will lead to some errors in the simulation results. This method is used to simulate the changes of lift-drag ratio and flight speed with different number of units. The simulation results of aerodynamic characteristics at an altitude of 2000 m are shown in Figure 4.



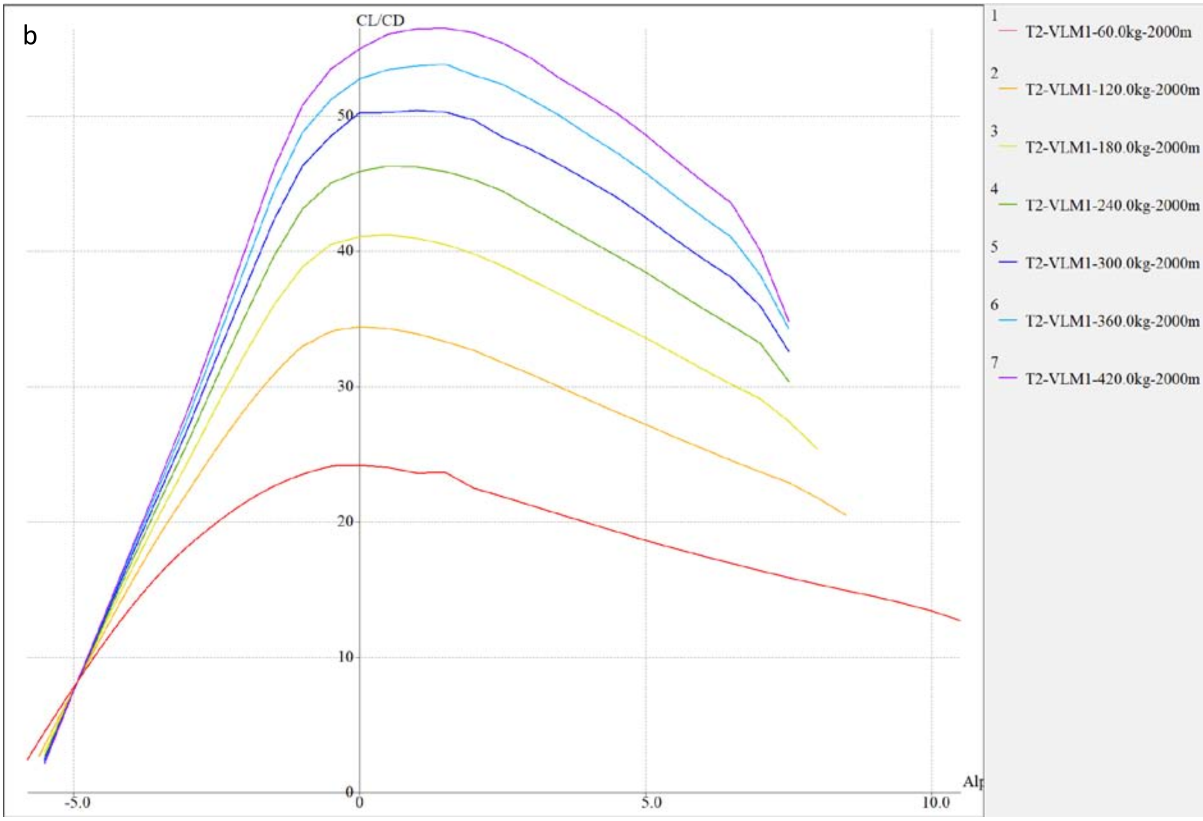


Figure 4: Variation of aerodynamic parameters vary with respect to the number of units in the assembly. (a) Variation of lift coefficient, resistance coefficient, torque coefficient and lift-drag ratio with respect to angle of attack. (b) Variation of lift-drag ratio with respect to angle of attack

See Table 1 for the sorted data, and draw Figure 5 for the simulation lift-drag ratio at 0° and the calculated theoretical lift-drag ratio. It can be seen that the law of lift-drag ratio approximately meets $\sqrt{n}$ times, and the failure to reach $\sqrt{n}$ times is caused by $e_n < 1$. This result is consistent with the conclusion in Section 2.1.

Table 1: Data of calculation and simulation

n	Simulated lift-drag ratio	Theoretical lift-drag ratio	Speed[m/s]	Lift coefficient	$C_{Ln} \cdot V_n^2$
1	24.161	24.161	42.00	0.553	975.49
2	34.397	34.164	39.38	0.629	975.44
3	41.050	41.847	38.40	0.661	974.68
4	45.870	48.322	37.88	0.679	974.29
5	50.199	54.024	37.56	0.691	974.83
6	53.539	59.170	37.34	0.699	974.60
7	56.095	63.930	37.18	0.705	974.56

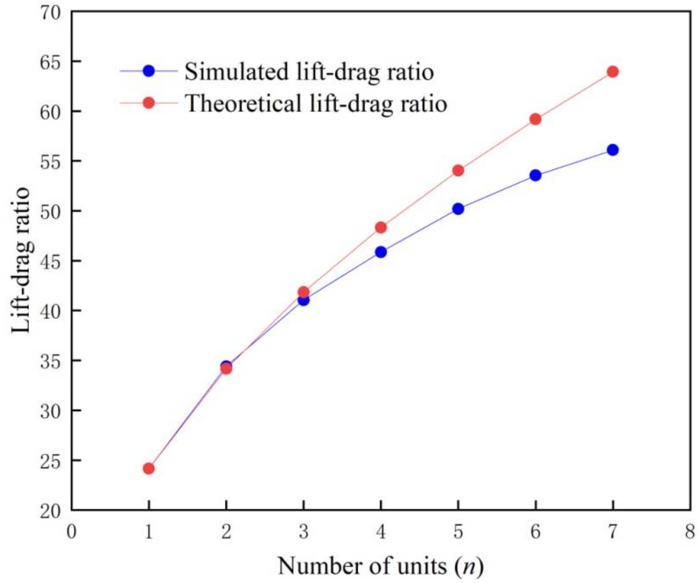


Figure 5: Relationship between lift-drag ratio and *1n*

Shown in Figure 6, two parameters of lift coefficient and flight speed with different *n* are extracted from the simulation results. It can be seen that the demand for cruise speed gradually decreases with the increase of *n*, thus reducing the consumption of power and energy. The relationship between $C_{Ln}{\cdot}V_n^2$ and *n* is shown in Figure 7, verifying equation (13), which is consistent with the conclusion in Section 2.2.

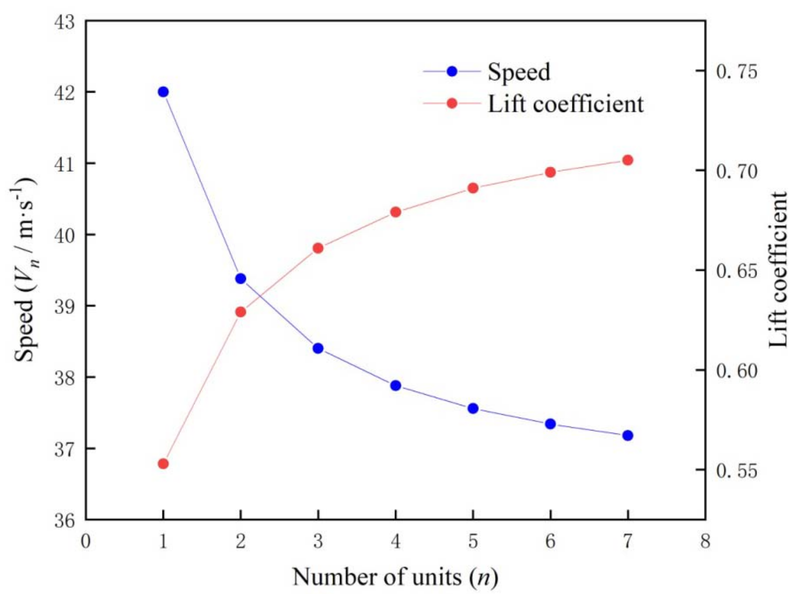


Figure 6: Relationship between lift coefficient, flight speed and *n*

Global Journal of Researches in Engineering (D) Volume XXIII Issue I Version I Year 2023

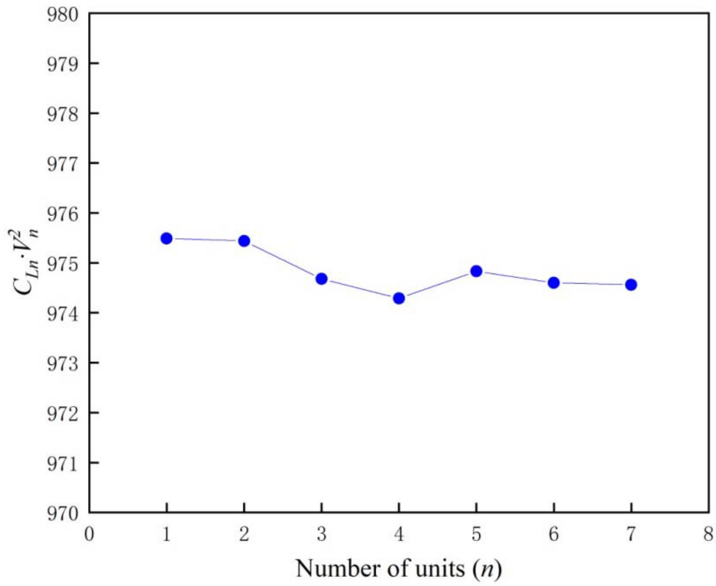


Figure 7: Relationship between $C_{Ln} \cdot V_n^2$ and n

IV. Effect of Wingtip Connection on Cruise Performance

In this section, it is assumed that the flight unit or combination will fly at a constant speed and level under the condition of force balance.

a) *Influence of Different Heights and Unit Numbers on Tensile Demand*

When n is constant, both G_n and S_n are constant, too. Then let equation (10) be reduced to $k_3 = \rho_n V_n^2 C_{Ln}$.

$$G_n = L_n = \frac{1}{2} S_n k_3 \tag{14}$$

It can be seen that G_n, S_n and k_3 remain unchanged when the height changes. Then equation (9) can be reduced to

$$F_n = D_n = \frac{1}{2} S_n k_3 \frac{1}{K_n} \tag{15}$$

That is, when the flight altitude changes, the pull required for the level flight of the combination is only related to the lift-drag ratio, which mainly depends on the flight speed and angle of attack [18], and is not sensitive to the altitude change, so the demand for pull at different altitudes is basically unchanged.

Using the model of Section 3, since the influence of the fuselage is not considered, the induced resistance is used to estimate the resistance of the whole aircraft. The induced resistance of the flight unit is calculated according to the following formula.

$$D_{i1} = \frac{1}{2} \rho_1 V_1^2 C_{Di1} S_1 \tag{16}$$

In the formula, the lower corner mark 1 represents the flight unit, and the induced resistance of the flight unit is calculated, D_{i1}=14.91N. The induced resistance of the small fixed wing UAV accounts for 25% ~ 40% of the total resistance. Here, the waste resistance of the flight unit is calculated according to the induced resistance accounting for 30% of the total resistance, D_{p1}=41.74N. Similarly, the induced resistance of the combination, D_{in}, can be obtained, while the waste resistance of the combination, D_{pn}, can be calculated using the following formula.

$$D_{pn} = n D_{p1} \frac{V_n^2}{V_1^2} \tag{17}$$

Then calculate the tensile demand of a single propeller through the following formula.

$$F_n = \frac{D_{in} + D_{pn}}{n} \tag{18}$$

The relationship between tensile force F_n and n is shown in Figure 8.

Table 2: Relationship between tensile force F_n and n

n	Tensile demand of single propeller F_n[N]
1	56.64
2	45.59
3	41.48
4	39.15
5	37.81
6	36.78
7	36.05

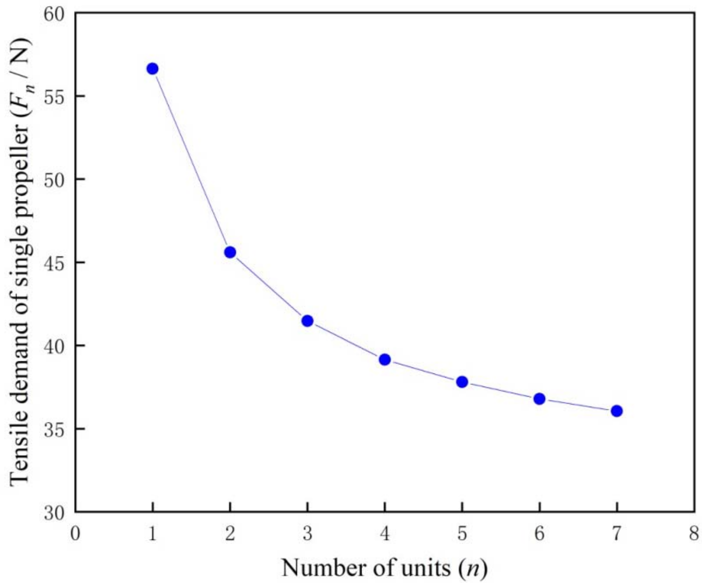


Figure 8: Relationship and trend between tensile force F_n and n

It can be seen that the required tension F_n decreases with the increase of n, and the change rate decreases.

b) Wingtip Connection can Raise the Ceiling

When estimating the resistance according to Section 4.1 using the model of section 3, for a motor drive, the 1.5:1 reduction mechanism and 16 × 8 APC propeller is calculated under 32 V power supply. The maximum pull of single propeller at different altitudes is shown in Table 3, and Figure 9 is drawn accordingly.

Table 3: Maximum tension at different altitudes

Altitude H[km]	Maximum pulling force F_{max} [N]	Altitude H [km]	Maximum pulling force F_{max}[N]
0	60.22	7	46.30
1	58.61	8	43.61
2	56.91	9	40.65
3	55.10	10	37.43
4	53.15	11	33.83
5	51.05	12	29.84
6	48.76		

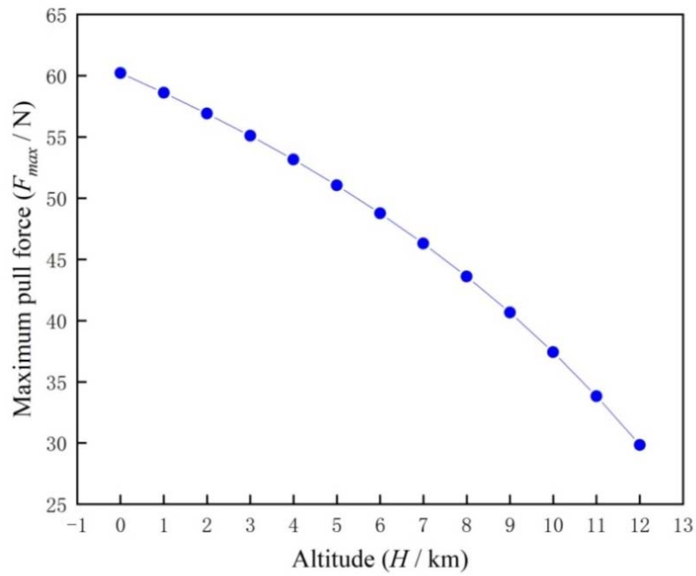


Figure 9: Relationship between altitude and maximum pulling force of single propeller

The fitting formula of the curve is obtained.

$$F_{\max} = -0.1037H^2 - 1.0283H + 61.071 \qquad (19)$$

Substituting the values of F_n in Table 2 into the formula above, the obtained results are the different ceiling with different n, and the results are shown in Table 4.

Table 4: Ceiling of different unit number

n	Tensile demand of single propeller F_n[N]	Ceiling H_{max}[km]
1	56.64	3.25
2	45.59	8.22
3	41.48	9.65
4	39.15	10.40
5	37.81	10.82
6	36.78	11.13
7	36.05	11.35

The relationship between n and the ceiling is shown in Figure 10.

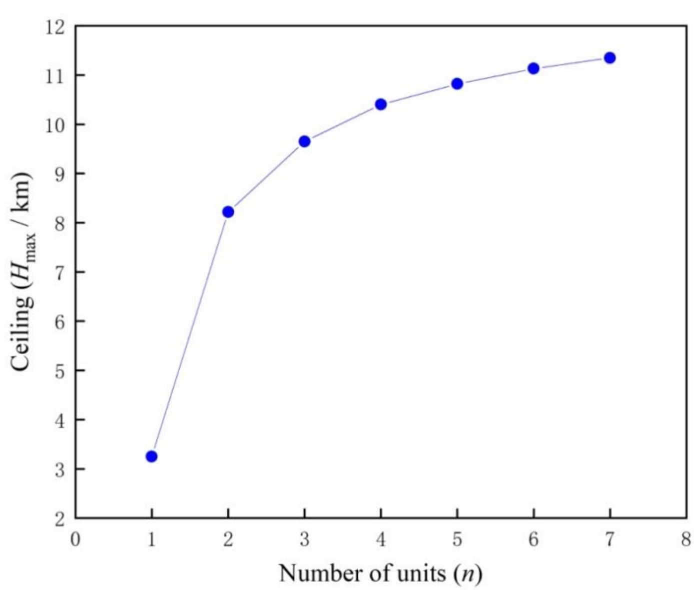


Figure 10: Relationship between n and the ceiling

It can be seen that increasing the number of flight units can effectively improve the ceiling of the aircraft. The ceiling increases with the increase of n, while the change rate decreases.

c) Wingtip Connection can Increase Endurance Time

Assuming a 128 Ah 32 V power supply is used and the combination flies horizontally at an altitude of 2 km, the working current and flight time of the combination with different n are calculated as shown in Table 5.

Table 5: Influence on working current and flight time 1n

n	Current [A]	Flight time [min]	Endurance improvement
1	29.93	256.6	0.00%
2	21.78	352.7	37.45%
3	18.97	404.8	57.76%
4	17.45	440.2	71.55%
5	16.59	463.0	80.44%
6	15.93	482.0	87.83%
7	15.48	496.2	93.37%

The relationship between n and flight time is shown in Figure 11.

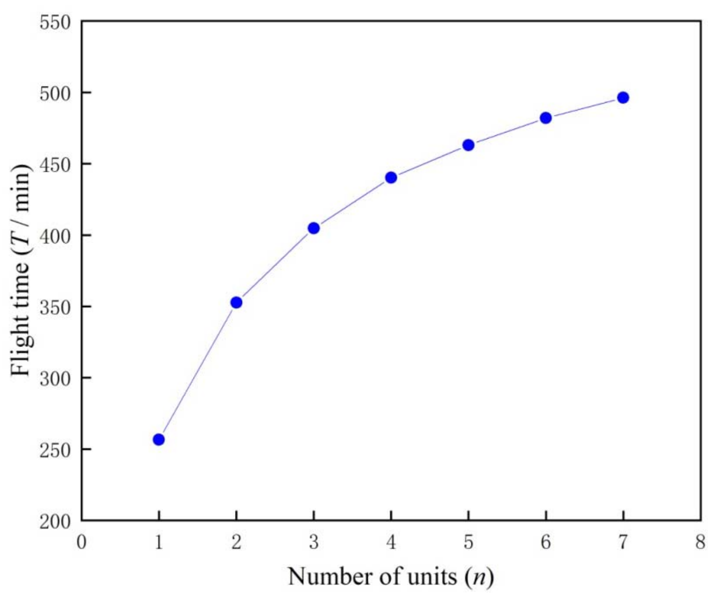


Figure 11: Relationship between n and flight time

It can be seen that increasing the number of flight units can effectively improve the flight time. The endurance time increases with the increase of n, while the change rate decreases.

V. Results and Discussion Conclusion

With the rise of cluster UAVs, wingtip connection technology has been paid attention again. Wingtip connection can make the flight unit fly higher, farther and more durable.

Firstly, the theoretical analysis of wingtip connection is carried out, and two conclusions are obtained through the theoretical analysis. First, the lift-drag ratio of the combination K_n is proportional to $\sqrt{ne_n}$, and the Oswald efficiency factor e_n decreases with the increase of n; The second is that the cruise speed of the combination V_n is inversely proportional to $\sqrt{C_{Ln}}$. Then, the correctness of the above two conclusions is verified by simulation. Based on this, the influence of wingtip connection on endurance performance is analysed, and the following conclusions are obtained. First, the flight altitude has little effect on the tensile demand, but tensile demand decreases with the increase of n, while the change rate decreases; The second is that the ceiling increases with the increase of n, while the rate of change decreases; Third, the endurance time increases with the increase of n, while the change rate decreases. Theoretically, increasing the number of units n can continuously improve the flight performance of aircraft.

However, as the number of assembly units increases, the ceiling and endurance benefits brought by connection gradually decrease. In addition, large-scale wingtip connections have high requirements for control systems and connecting mechanisms. Too many units will lead to more complex control and connecting mechanisms with greater loads. Therefore, the number of wingtip connections is not the more the better.

Data Availability

The aerodynamic parameters in this paper are calculated by xflr5 v6.48, and the file has been uploaded. The file name is *model.xfl*.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgments

The authors are grateful for the financial support from the China Aviation Science Foundation Program (201829U8007). They would also like to thank the Aeromodelling Team of RFUE for providing support.

References Références Referencias

1. X. Wang, Z. Liu, Y. Cong, et al., "Miniature fixed wing UAV swarms: review and outlook," *Acta Aeronautica et Astronautica Sinica*, vol. 41, no. 4, pp. 20-45, 2020.
2. M. Wu, Z. Shi, T. Xiao, et al., "Effect of wingtip connection on the energy and flight endurance performance of solar aircraft," *Aerospace Science and Technology*, vol. 108, pp. 106404, 2021.
3. C. Anderson, "Dangerous experiments: wingtip coupling at 15,000 feet," *Flight Journal*, vol. 5, no. 6, pp. 64-72, 2000.
4. S. A. Magill, "Compound aircraft transport study: wingtip-docking compared to formation flight," *Virginia Polytechnic Institute and State University*, Blacksburg, Virginia, USA, 2002.
5. C. Montalvo, "Meta aircraft flight dynamics and controls," *Georgia Institute of Technology*, Atlanta, Georgia, US, 2014.
6. C. Montalvo, M. Costello, "Meta aircraft flight dynamics," *Journal of Aircraft*, vol. 52, no. 1, pp. 107-115, 2015.
7. C. Montalvo, M. Costello, "Meta aircraft connection dynamics," in *AIAA guidance, navigation, and control conference.* Minneapolis, Minnesota, USA, 2012.
8. C. Collin, C. Montalvo, "Experimental control of two connected fixed wing aircraft," *Aerospace*, vol. 113, no. 5, pp. 1-13, 2018.
9. M. Cobar, C. Montalvo, "Takeoff and Landing of a Wing-Tip-Connected Meta Aircraft with Feedback Control," *Journal of Aircraft*, vol. 58, no. 4, pp. 733-742, 2021.
10. J. R. Cooper, P. M. Rothhaar, "Dynamics and control of in-flight wing tip docking," *Journal of Guidance Control & Dynamics*, vol. 41, no. 11, pp. 2327-2337, 2018.
11. S. Wlach, G. Balmer, M. Hermann, et al., "ELAHA-elastic aircraft for high altitudes concept and current development state of an unconventional stratospheric UAV," in *23rd ESA Symposium on European Rocket and Balloon Programmes and Related Research*. Visby, Sweden, 2017.
12. A. Köthe, A. Behrens, A. Hamann, et al., "Closed-loop flight tests with an unmanned experimental multi-body aircraft," in *17th International Forum on Aeroelasticity and Structural Dynamics*. Como, Italy, 2017.
13. R. Zhou, W. Zhou, D. Wang, et al., "Overview of UAV link wing system technology," in *the 5th Joint Conference of Aerospace Propulsion (JCAP) Technical Conference*. Nanjing: 2020: 2336-2344.
14. Y. Yang, Z. Zhang, P. Ying, et al., "Flexible modular swarming UAV: innovative, opportunities, and technical challenges," *Flight Dynamics*, vol. 39, no. 2, pp. 1-9+15, 2021.
15. W. Zhou, P. Ma, Z. Guo, et al., "Research progress of combined fixed-wing unmanned aerial vehicle based on wingtip chained," *Acta Aeronautica et Astronautica Sinica*, vol. 43, no. 9, pp. 606-622, 2022.2022, 43(09): 606-622.
16. C. An, C. Xie, Y. Meng, et al., "Flight mechanical analysis and test of unmanned multi-body aircraft," in *International Forum on Aeroelasticity and Structural Dynamics.* Savannah, Georgia, USA, 2019.
17. T. Chen, J. Katz, "Induced drag of high-aspect ratio wings," in *42nd AIAA Aerospace Sciences Meeting and Exhibit*, Reno, Nevada, USA, 2004.
18. Z. Fang, W. Chen, S. Zhang, *Flight dynamics of aircraft*, Beihang University Press, Beijing, 2005.

This page is intentionally left blank

Global Journal of Researches in Engineering: D
Aerospace Science
Volume 23 Issue 1 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Synthesis and Research of Filter with a Variation of Coefficients for Tracking a Maneuvering Aerodynamic Target

By Uladzimir A. Aparovich

Abstract- Processing radar information about aerodynamic targets, coordinate information remains an urgent problem. It is assumed that the target moves in a straight line and evenly most of the time, and less of the time, it makes various maneuvers. Target tracking is carried out at a rate equal to the survey time, in the presence of coordinates measurements. Currently, there are number of filters for smoothing the target coordinate parameters. At the same time, the existing filters are characterized by a large error of smoothing in sections without a maneuver and small in sections with a maneuver, or vice versa - by a small error in sections without a maneuver and a large error in sections with a maneuver. Moreover, many filters work effectively only in some specified ranges of input parameters. The new filter should provide a minimum smoothing error in areas without maneuver. It should ensure the minimum possible errors and emissions of smoothing error during the maneuver and operate efficiently over the widest range of input parameters.

Keywords: radar information processing, maneuver, aerodynamic target, smoothing of coordinates, variation of coefficients.

GJRE-D Classification: DDC Code: 621.51 LCC Code: TJ990

SYNTHESISANDRESEARCHOFFILTERWITHAVARIATIONOFCOEFFICIENTSFORTRACKINGAMANEUVERINGAERODYNAMICTARGET

Synthesis and Research of Filter with a Variation of Coefficients for Tracking a Maneuvering Aerodynamic Target

Uladzimir A. Aparovich

Annotation- Problem Formulation: Processing radar information about aerodynamic targets, filtering of coordinate information remains an urgent problem. It is assumed that the target moves in a straight line and evenly most of the time, and less of the time, it makes various maneuvers. Target tracking is carried out at a rate equal to the survey time, in the presence of errors of coordinates measurements. Currently, there are number of filters for smoothing the target coordinate parameters. At the same time, the existing filters are characterized by a large error of smoothing in sections without a maneuver and small in sections with a maneuver, or vice versa - by a small error in sections without a maneuver and a large error in sections with a maneuver. Moreover, many filters work effectively only in some specified ranges of input parameters.

Aim: The new filter should provide a minimum smoothing error in areas without maneuver. It should ensure the minimum possible errors and emissions of smoothing error during the maneuver and operate efficiently over the widest range of input parameters.

Results: To achieve this goal, a two-fold correction (variation) of the smoothing coefficients was used in accordance with the deviation of the coordinate of the newly measured position of the target (mark) from the extrapolated position. The variation is performed in accordance with the selected function, while the smoothing step acquires a certain conditional value. The proposed filter has been simulated. The comparison results show a significant decrease in the root-mean-square errors of smoothing the coordinates and velocity of the proposed filter in comparison with other samples in a wide range of parameters.

Practical Significance: The new filter can be used in various systems for processing radar information as more affective.

Abstract- Processing radar information about aerodynamic targets, coordinate information remains an urgent problem. It is assumed that the target moves in a straight line and evenly most of the time, and less of the time, it makes various maneuvers. Target tracking is carried out at a rate equal to the survey time, in the presence of coordinates measurements. Currently, there are number of filters for smoothing the target coordinate parameters. At the same time, the existing filters are characterized by a large error of smoothing in sections without a maneuver and small in sections with a maneuver, or vice versa - by a small error in sections without a maneuver and a large error in sections with a maneuver. Moreover, many filters work effectively only in some specified ranges of input parameters. The new filter should provide a minimum smoothing error in areas without maneuver. It should ensure the minimum possible errors and emissions of smoothing error during the maneuver and operate efficiently over the widest range of input parameters. To achieve this goal, a two-fold correction (variation) of the smoothing coefficients was used in accordance with the deviation of the coordinate of the newly measured position of the target (mark) from the extrapolated position. The variation is performed in accordance with the selected function, while the smoothing step acquires a certain conditional value.

Algorithm of recurrent smoothing includes some steps:

- We receive a new value of coordinate.
- The old value of coordinate extrapolates on time of mark.
- Then we calculate the mean of gate.
- Then we obtain the variation of conditional smoothing step (the first variation) with accordance to selected function. Then we change smoothing coefficients with accordance to deviation, mean of gate and new smoothing step.
- We calculate new smoothing coordinate, velocity and new conditional smoothing step (second variation).

The proposed filter modelling has been performed. Received by modelling values of smoothing errors were compared with smoothing errors of other filters, described in scientific literature. Tree literature sources with 9 filters of different types were used. The comparison results demonstrate a significant decrease in smoothing of the root mean square errors of coordinates and velocity in the proposed filter in comparison with other samples; with according to main requirements, any “tunes” in proposed filter were not used.

The new filter can be used in various systems for processing radar information as more affective.

Keywords: radar information processing, maneuver, aerodynamic target, smoothing of coordinates, variation of coefficients.

I. Introduction

Currently, there is a large number of filters for tracking maneuvering aerodynamic targets used for processing radar information [1 - 8]. According to [1], such filters are divided into four types:

- without maneuver detection (WMD);
- with maneuver detection (MD);
- multialternative (IMM-filters);
- other, "exotic" (for example, particle filters).

Author: OJSC “AGAT – Control Systems” – Managing Company of “Geoinformation Control Systems Holding” (Minsk, Republic of Belarus). e-mail: aporovich@agat.by

At the same time, the task of providing effective smoothing remains relevant, and all types of filters have their drawbacks. As a rule, the first two types are characterized by small smoothing errors in those sections of the target trajectory where there is no maneuver, and large errors in the maneuver sections. As a rule, there are large errors during the maneuver. The third type, due to its internal settings, allows you to change the ratio of errors in the maneuver sections and its absence within a wide range. According to the literature, variants are often used, where relatively small errors are provided in the maneuver sections and large errors in its absence. In addition, many variants of filters of all types are a priori "tuned" to certain values of the intensity of the maneuver. This leads to the fact that smoothing errors significantly increase when the maneuver intensity parameters deviate from the settings.

The use of "exotic" filters has not yet shown an increase in filtration efficiency.

II. Aim of Work

When synthesizing the filter described in this article, the task was to create a filter that satisfies the following requirements:

– Filter should provide a minimum smoothing error in areas without a maneuver;
– Filter should provide the minimum possible errors and smoothing error during the maneuver;
– Filter should provide effective smoothing when the initial parameters change over a wide range (for example, maneuver intensity, measurement errors, review period - information updates), that is, the filter should not contain any settings.

III. Proposed Way to Solve the Problem

To solve the problem in this filter it is proposed to use random values of deviation of coordinate of newly measured target position (marker) from its extrapolated position. This deviation is proposed to be used to adjust the smoothing coefficients in order to consistently track the potential beginning of the maneuver. We assume that such tracking will increase the efficiency of filtering. In fact, in the particle filter such deviation is specifically generated. Here, in contrast to the particle filter, this random deviation is not generated artificially, but is taken already "ready".

Hereinafter the new filter will be called a filter with variation of coefficients (FVC).

As an initial analogue, we use an equal-precision, equal-discrete filter from [8], which is a variant of the Kalman filter for a linearly changing coordinate. Basic ratios for this filter:

$$Xp_i = Xs_{i-1} + VXs_{i-1} \cdot T\,; \qquad (1)$$

$$A_i = \frac{2(2 \cdot i - 1)}{i(i+1)}\,; \qquad (2)$$

$$B_i = \frac{6}{i(i+1)}\,; \qquad (3)$$

$$\Delta X_i = X_i - Xp_i\,; \qquad (4)$$

$$Xs_i = Xp_{i-1} + A_i \cdot \Delta X_i\,; \qquad (5)$$

$$VXs_i = VXs_{i-1} + B_i \cdot \frac{\Delta X_i}{T}\,, \qquad (6)$$

where: Xp_i is the extrapolated value of the X coordinate on i-th moment (period) of filtration;

Xs_{i-1}, VXs_{i-1} are the smoothed values of the X coordinate and the rate of its change on the $(i-1)$-th moment;

A_i, B_i are the smoothing coefficients at the i-th moment for the coordinate and velocity, respectively;

ΔX_i is the difference between the measured value of the X coordinate on the i-th moment and the extrapolated value of Xp_i;

Xs_i, VXs_i are the smoothed values of the coordinate and velocity on the i-th moment of time;

T - the period of receipt of marks (review period).

In this analogue filter, the values of the smoothing coefficients A_i and B_i depend only on the i step. When the i values increase, A_i and B_i monotonically decrease, which means that we more and more “trust” our smoothed (extrapolated) values and less and less “trust” the newly incoming information (marks). It is known that such a filter for maneuvers of the target (deviation from rectilinear uniform motion) at sufficiently large i values will give a large value of smoothing errors.

When synthesizing the FVC, lets fulfill the following conditions:

a) The smoothing coefficients should increase with increasing ΔX_i deviation and decrease with ΔX_i decreasing. The smaller the deviation, the less we “trust” him, and the more, the more we “trust” it. It allows you to quickly track the start of the maneuver by successive ΔX_i increase. Note that the smoothing coefficients become, as it were, “random”.
b) The average value of the smoothing coefficients should not differ from the values calculated by formulas (2) and (3) in order to ensure effective

Global Journal of Researches in Engineering (D) Volume XXIII Issue I Version I Year 2023

smoothing in the absence of a maneuver. No worse than in analogue filter.

To fulfill conditions a.) and b.), we choose a function for adjusting the coefficients. The form of the proposed function for the coefficient A is shown in fig. 1.

On fig. 1 An_i is the resulting value of the coefficient to be used in formula (5) instead of A_i.

The value An_i must be such that the average An_i value for all ΔX_i is close to or equal to A_i to fulfill the condition b.). When the value ΔX_i (possible maneuver) is increased, the An_i value must increase.

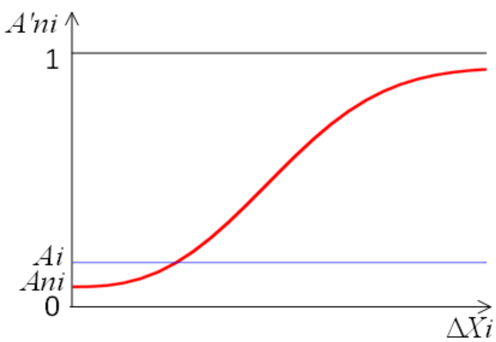


Fig. 1: Function type for adjustment of coefficient A

IV. Algorithm of FVC Operation

The finished FVC algorithm includes the actions listed below. Initial values for the filter are calculated according to Table 1 [9].

Table 1: Initial values for the filter

i	A_i	B_i	Xs_i	VXs_i
1	1	1	X_i	–
2	1	1	X_i	$\frac{X_2 - X_1}{T}$

We also input a new parameter "conditional step" (CS) in_i for the i-th step. The initial value of the CS is 3. We assume that we know the root-mean-square error (RMSE) of σX coordinate measuring.

The sequence of actions of the algorithm for $i > 2$.

1. Start. Getting a new X_i value.
2. Extrapolation of X coordinate by formula (1).
3. Calculation of tracking strobe size by X coordinate:

$$\Delta c X_i = \sigma X \cdot Kg \cdot Kc_i,$$

where Kg is the confidence coefficient (usually 3);

Kc_i is a strobe coefficient, which takes into account the RMSE of extrapolation and measurement [10]:

$$Kc_i = \sqrt{\frac{2(2 \cdot in_i - 1)}{(in_i - 1)(in_i - 1)} + 1}$$

4. First adjustment of the CS. We "increase" the CS, so that later we get An_i value less than A_i value according to formula (2), in accordance with Fig. 1:

$$i'n_i = K \cdot (in_i - 1) + 1$$

where K is some increase coefficient of the step value. Note that the CS ceases to be an integer [10].

5. Calculation of the smoothing factor for CS according to formula (2):

$$An_i = \frac{2(2 \cdot i'n_i - 1)}{i'n_i (i'n_i + 1)};$$

6. Deviation calculation according to formula (4).
7. Relative Deviation Calculation

$$\delta X_i = \left| \frac{\Delta X_i}{\Delta c X_i} \right|.$$

8. Correction of the An_i smoothing factor according to δX_i. The adjustment implements the function shown in fig. 1, but it is taken δX_i instead of ΔX_i.

$$A'n_i = 1 - (1 - An_i) \cdot Kor,$$

$$\text{where } Kor = \exp\left(-\frac{\delta X_i^{\,S}}{S_S}\right); \quad S = \log\left(\frac{Am}{An_i}\right) + 2; \quad S_S = 2 \cdot \frac{Am}{An_i},$$

Am is fiducial value of A.

The proposed formulas for $A'n_i$ calculation shows:

- Normality of random processes;
- The need to provide the type of function for as in fig. 1.

9. Calculation of the new value of CS. The expression for CS was obtained from (2) by solution a quadratic

equation, where $A_i\left(A'n_i\right)$ is the argument and $i\left(i'n_i\right)$ is the desired value:

$$i'n_i = \frac{4 - A'n_i + \sqrt{\left(A'n_i - 4\right)^2 - 8A'n_i}}{2A'n_i + 1}.$$

10. Calculate the velocity smoothing coefficient using formula (3):

$$B'n_i = \frac{6}{i'n_i\left(i'n_i + 1\right)}$$

11. Calculation of the smoothed values by (5) and (6):

$$Xs_i = Xp_{i-1} + A'n_i \cdot \Delta X_i\,;\; VXs_i = VXs_{i-1} + B'n_i \cdot \frac{\Delta X_i}{T}.$$

12. Modification of the CS to the next i step. The i value is modified by one. Here we introduce the CS i_{nm} constraint [4]:

$$in_i = \begin{cases} i'n_i + 1, \text{ if } i'n_i + 1 \le i_{nm}; \\ inm, \text{ if } i'n_i + 1 > i_{nm}. \end{cases}$$

Experimental conditions are described in Table 3.

Further, when a new X_i value is obtained, actions 1) ... 12) are repeated.

Recommended parameter values for FVC are given in Table 2.

Table 2: Recommended parameter values for FVC

Parameter	Meaning
K	1,3 for $in_i < 50$ 1,05 for $in_i \ge 50$
Am	0,2
i_{nm}	20

V. Simulation Results

The effectiveness of the FVC was evaluated using simulation modeling. For comparison, we used filters from those articles and books where the description can unambiguously determine the conditions of the experiment and interpret its results.

Table 3: Experimental conditions

Characteristic	Literary source		
	[6]	[2]	[3]
Initial velocity	$VX = 10$ m/s	$VX = -426$ m/s; $V_Y = 0$ m/s	$VX = 300$ m/s
Initial position X, Y	–	$X = 120\ 000$ m; $Y = 2\ 000$ m	–
Period T, s	1	1	2
Maneuver period, maneuver acceleration	50 – 70 s $aX = 5\,\text{m/s}^2$	31 – 38 s $aX = 5\,\text{m/s}^2$; $aY = -10\,\text{m/s}^2$	22 – 46 s Centripetal (g - acceleration of gravity)
		38 – 49 s $aX = -8\,\text{m/s}^2$; $aY = 18\,\text{m/s}^2$	
		49 – 61 s $aX = 10\,\text{m/s}^2$; $aY = -20\,\text{m/s}^2$	
		61 – 65 s $aX = 0\,\text{m/s}^2$; $aY = 30\,\text{m/s}^2$	
		65 – 66 s $aX = -10\,\text{m/s}^2$; $aY = -8\,\text{m/s}^2$	
		66 – 81s $aX = -5\,\text{m/s}^2$; $aY = 0\,\text{m/s}^2$	
		81 – 90 s $a = 5\text{м/с}$; $aY = -10\,\text{m/s}^2$	

End of experiment	120 s and 240 s	90 s	80 s
RMSE	σX=5 m	Azimuth 0.02 rad, range 67.5 m	σX=250 m
Tested filters and their types	«VSD» - MD «AI» - IMM «VPN» - IMM	«AWN» - MD «CM» - IMM «VDF» - MD	«Method1a» - WMD «Method4a» - MD «Method5a» - IMM

The simulation results for various filters from [6, 2, 3] and FVC are shown in Figs. 2 - 5 and in table 4. Figures 2 – 4 show the dependences of the smoothed RMSE σSX along the X coordinate on t time (the graphs are plotted by characteristic points). Figure 2 shows dependences for [6], in fig. 3 – for [2], in fig. 4 - for [3]. Figure 5 shows the dependences of the RMSE of the σSVX smoothed velocity along the X coordinate for the filters from [6] and FVC.

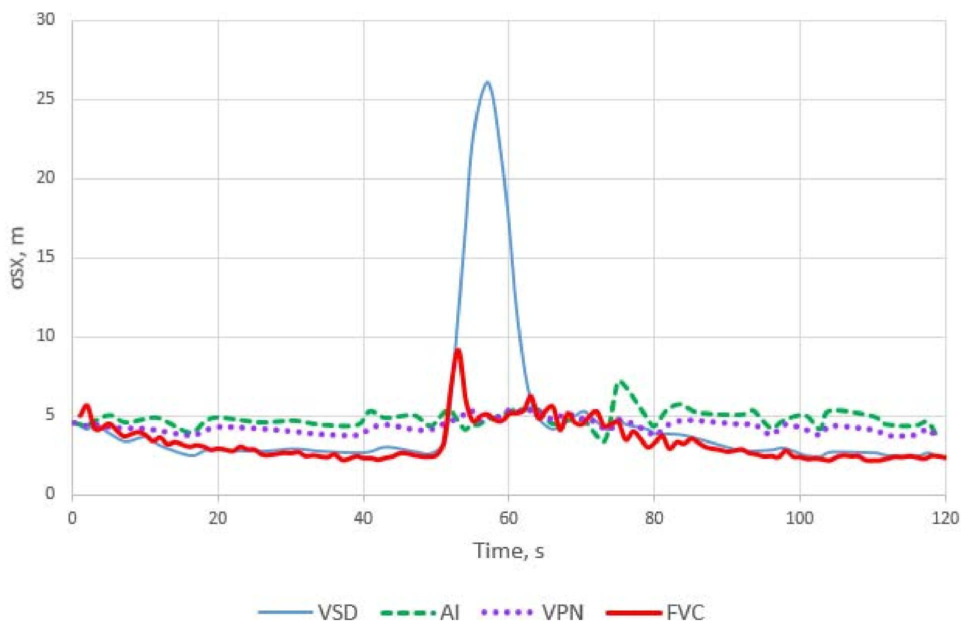


Fig. 2: Dependence of smoothed RMSE σSX on Time t for filters of [6] and FVC

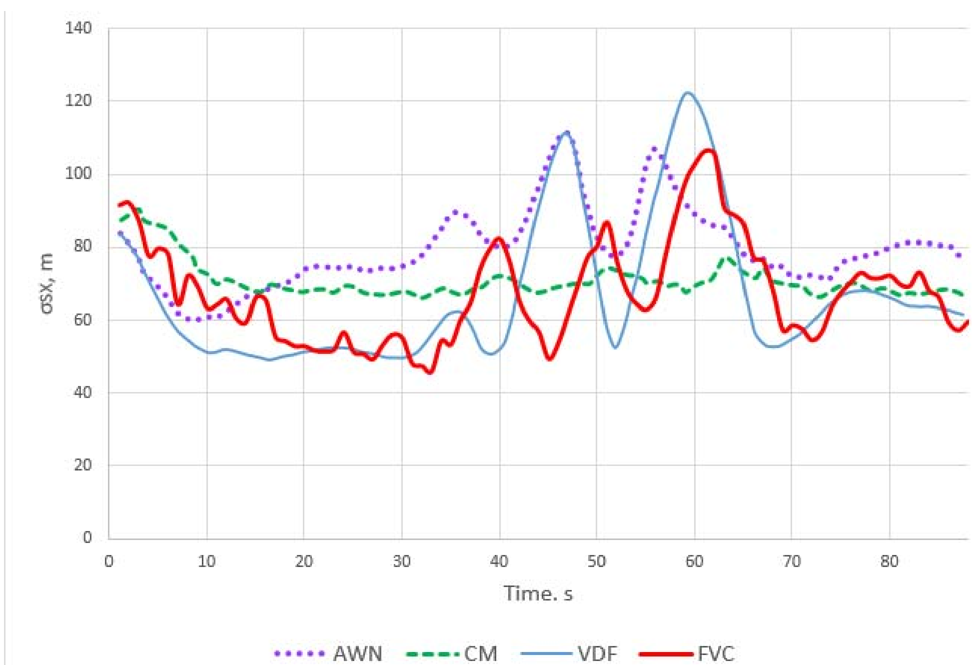


Fig. 3: Dependence of smoothed RMSE σSX on Time t for filters of [2] and FVC

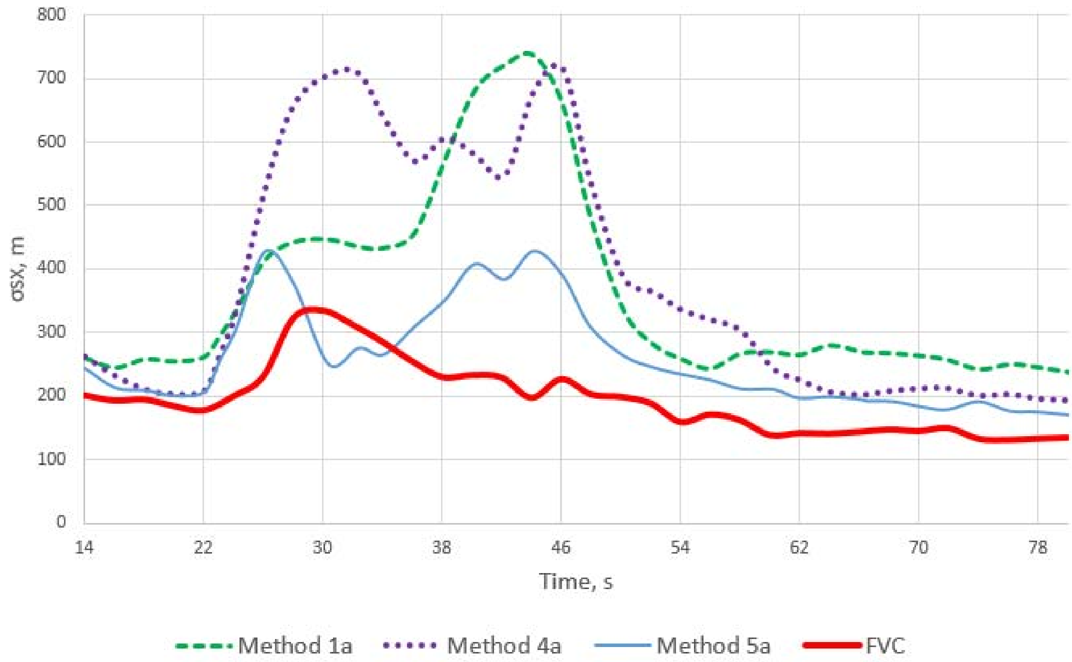


Fig. 4: Dependence of smoothed RMSE σSX on Time t for filters of [3] and FVC

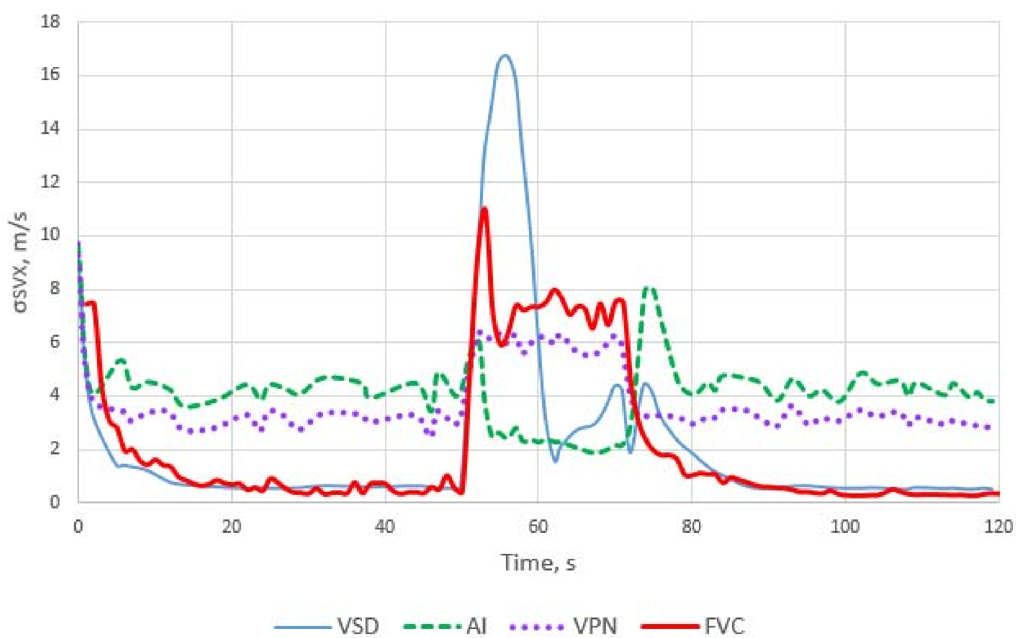


Fig. 5: Dependence of RMSE of smoothed velocity σSVX on Time t for filters of [6] and FVC

Table 4 shows the values of the total RMSE for all filters for two experiments.

Table 4: Values of the general RMSE for the filters from [6] and FVC

Filter	Experiment duration			
	240 s		120 s	
	σSX, m	σVSX, m/s	σSX, m	σVSX, m/s
VPN	4,12	3,51	4,35	4,30
VSD	4,92	2,92	7,88	5,17
AI	4,64	4,21	4,72	4,30
FVC	2,98	2,40	3,54	3,40

VI. The Discussion of the Results

An analysis of the simulation results shows that the FVC provides a higher quality of smoothing (lower RMSE of the smoothed parameter) compared to other filters - see, for example, Table 4. Compared to the WMD and MD filters (VSD, AWN, Method 1a, Method 4a) FVC provides a smaller value of the error in the maneuver section. At the same time, the efficiency of smoothing in the absence of a maneuver does not decrease, as with filters of the IMM type (AI, VPN, CM, Method 5a - Fig. 2 - 5). The effectiveness of the FVC does not decrease with the input error value, scanning interval, intensity and duration of the maneuver.

VII. Conclusion

The proposed FVC does not contain maneuver detection means. It belongs to the WMD type.

An analysis of the simulation results shows that the FVC for tracking a maneuvering aerodynamic target provides a higher efficiency (lower value of the smoothed RMSE) compared to various other types and variants of filters and can be used in radar information processing systems.

It was achieved by introducing a new mechanism for adjusting the smoothing coefficients, taking into account the deviation of the mark coordinates from the extrapolated target position. At the same time, the proposed filter does not contain any settings for input errors, target maneuver parameters, review period, other factors.

References Références Referencias

1. Konovalov A. A. Osnovy trajectornoj obrabotki radiolokacionnoj informacii: v 2 ch. CH 2. SPb: SPbGETU “LETI”. 2014.
2. He Yon, Xin Jianjuan, Guan Xin. *Radar Data Processing with Applications*. Publishing house of Electronic Industry. Singapore; 2016.
3. Blackman S., Popoli R. *Design and Analysis of Modern Tracking Systems*. Artech House. Boston – London; 1999.
4. Kuz’min S. Z. Cifrovaya radiolokaciya. Kiev: KVIC. 2000.
5. Bar-Shalom Y., Rong Li X., Thiagalingam Kirubarajan. *Estimation with Applications to Tracking and Navigation*. John Wiley & Sons, Inc.; 2001.
6. Yang Chun, Blasch Eric. Characteristic Errors of the IMM Algorithm under Three Maneuver Models for an Accelerating Target. *11th International conference of Information Fusion*. IEEE, Cologne, Germany; 2008.
7. Bakulev P. A., Sychov M. I., Nguen Chong Lyu. Mnogomodel’nyj algoritm soprovozhdeniya traektorii manevriruyushchej celi po dannym obzornoj RLS//Radiotekhnika. 2004. № 1. S. 26-32.
8. Hmarskij P. A., Solonar A. S. Osobennosti realizacii adaptivnyh diskretnyh fil’trov Kalmana pri kosvennyh izmereniyah. Doklady BGUIR. 2012. № 8(70). S. 57-63.
9. Kuzmin S. Z. Osnovy teorii cifrovoj obrabotki radiolokacionnoj informacii. M.: Sov. radio. 1974.
10. Aparovich U. A. Neravnotochnyj i neravnodiskretnyj fil’tr tablichnogo sglazhivaniya koordinat // Radiotekhnika. 1997. № 3. S. 43 45.

This page is intentionally left blank

Global Journal of Researches in Engineering: D
Aerospace Science
Volume 23 Issue 1 Version 1.0 Year 2023
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Experiment-based Internal Ballistics Simulation of Dual-Thrust Solid Rocket Motors

By Alaa R Abdel Gawad, Liang Guozhu & Mahmoud Y. M. Ahmed
Beihang University (BUAA)

Abstract- A key aspect to a successful simulation of the flow inside the Dual Thrust Solid Rocket Motor (DTSRM) is the proper definition of boundary and operating conditions as well as fluid properties. The experimental pressure-time curve was analyzed and divided into five regimes to be used as inputs for numerical simulations to understand the flow features inside an experimental DTSRM motor and to estimate its thrust. The entire motor operation time from ignition to tail-off was examined including two steady-state phases; boost and sustain, and three transient phases, ignition, boost-sustain transition, and tail-off. The grain burnback analysis was carried out to obtain the computational domain for each simulation. The operating pressure for each simulation is defined as equal to the measured chamber pressure which was measured at the head end of the motor. The results confirmed the capabilities of simulations to explore the flowfield inside the motor and to predict its thrust with remarkable accuracy of less than 5% relative to the experimental measurements in lieu of analytical calculations that are more suited for preliminary calculations and only offer accuracy of about 15% relative to experimental measurements.

Keywords: *dual-thrust solid rocket motor, internal ballistics, grain burnback, numerical simulation.*

GJRE-D Classification: *DDC Code: 519.2 LCC Code: QA273*

EXPERIMENTBASEDINTERNALBALLISTICSSIMULATIONOFDUALTHRUSTSOLIDROCKETMOTORS

Strictly as per the compliance and regulations of:

Experiment-based Internal Ballistics Simulation of Dual-Thrust Solid Rocket Motors

Alaa R Abdel Gawad α, Liang Guozhu σ & Mahmoud Y. M. Ahmed ρ

Abstract- A key aspect to a successful simulation of the flow inside the Dual Thrust Solid Rocket Motor (DTSRM) is the proper definition of boundary and operating conditions as well as fluid properties. The experimental pressure-time curve was analyzed and divided into five regimes to be used as inputs for numerical simulations to understand the flow features inside an experimental DTSRM motor and to estimate its thrust. The entire motor operation time from ignition to tail-off was examined including two steady-state phases; boost and sustain, and three transient phases, ignition, boost-sustain transition, and tail-off. The grain burnback analysis was carried out to obtain the computational domain for each simulation. The operating pressure for each simulation is defined as equal to the measured chamber pressure which was measured at the head end of the motor. The results confirmed the capabilities of simulations to explore the flowfield inside the motor and to predict its thrust with remarkable accuracy of less than 5% relative to the experimental measurements in lieu of analytical calculations that are more suited for preliminary calculations and only offer accuracy of about 15% relative to experimental measurements.

Keywords: dual-thrust solid rocket motor, internal ballistics, grain burnback, numerical simulation.

I. Introduction

The Dual Thrust Solid Rocket Motors (DTSRMs) are solid propellant rocket motors that have the capability of yielding a dual (step) thrust; a high thrust followed by a lower one. This boost-sustain feature finds applications in a variety of guided missiles. Boosting the missile allows it to swiftly accelerate to the nominal flight speed in a minimum uncontrolled flight time. The subsequent low thrust ensures near-zero acceleration to maintain the nominal flight speed (proper for control) for a maximum controlled flight time.

A dual thrust is achieved by different motor designs including single-chamber and single fixed nozzle, single-chamber and single variable nozzle, double-tandem chamber and single external nozzle, double-chamber and double nozzle configurations. Nonetheless, the simplest design is the one in which one chamber incorporating two grains of different configurations is used. This simplicity comes with motor operation complexity as it involves five different phases including two steady-state phases and three transient phases (ignition, transition, and tail-off).

Understanding the SPRM operation is a crucial step in missile mission design. Experimental measurements of chamber pressures and motor thrust are perhaps the most reliable in defining the overall motor operation. Nevertheless, practice shows that variable thrust measurement of DTSRM may be troublesome due to variation in thrust level. While measuring pressure can be simply achieved, the use of two different load cells for the same motor may not be as simple. Analytical techniques based on solving internal ballistic relations may also be used to estimate the motor pressure and thrust. However, if it is sought to understand the flow behavior and explore its features along the motor, neither experimentation nor analytical technique is the right approach. Numerical simulation of the flow along the DTSRM gives a better understanding of the multiple flow features associated with the two levels of pressure including streamlines, pressure, temperature, density, and velocity variation along the motor which cannot be attained from experimental measurements or analytical calculations. In addition, both numerical simulations and analytical calculations have the advantages of higher flexibility and lower cost and risk compared with experimental measurements. Yet, numerical simulations have higher fidelity compared with analytic calculations. One key aspect of the successful simulation is the proper definition of operating and boundary conditions. Using accurate experiment-based inputs would indeed yield more reliable simulation results.

The use of numerical simulation via the computational fluid dynamics (CFD) approach to understand and analyze the flow field through solid-propellant rocket motors has been widely adopted [1-8]. Some researchers focused on the ignition transient phase [9-15] to investigate phenomena accompanied by starting transient such as internal flow chocking, pre-ignition chamber dynamics, and boundary layer displacement. While some focused on quasi-steady-state and tail-off phases [16] to analyze the validity of performance prediction for parameters such as pressure, thrust, and nozzle throat variation. Pressure oscillation and acoustic instability taking place in the solid rocket were also addressed using numerical simulation [17-21]. Recently, more attention has been paid to using CFD in simulating solid rocket motors regression [22]. Li et al.

Author α: Ph.D. Candidate, School of Astronautics, Beihang University (BUAA), Beijing, China. e-mail: alaarabie@buaa.edu.cn
Author σ: Professor, School of Astronautics, Beihang University (BUAA), Beijing, China.
Author ρ: Ass. Professor, Aerospace Department, Military Technical College, Cairo, Egypt.

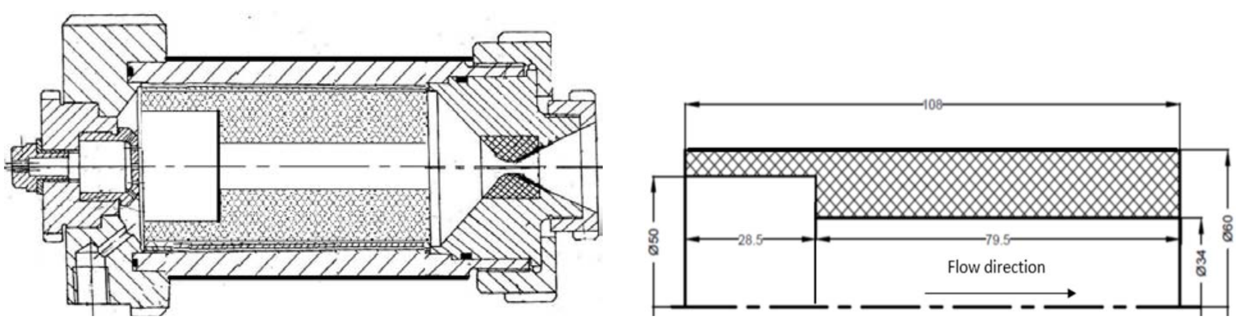
[23] presented an integrated framework for coupled simulation of internalfluid flow in a solid rocket motor and burning surface regression of propellant. Lin [24] developed an immersed boundary method to avoid the cumbersome re-meshing for simulating the coupling of gas flow and burning surface regression in solid rocket motors. Zou et al. [25] developed a numerical model to investigate the regression rate and the combustion process of a combined solid rocket motor for different grain inner diameters. Some advanced topics related to numerical simulation for solid rocket motors have been discussed. Han and Kim [26] examined the interaction between burning module, structure, and fluid inside solid rocket motors. Hemanth and Jyothi [27] simulated the flow inside a retro solid-propellant rocket motor.

The objective of the present work is to simulate the flow inside a DTSRM using computational fluid dynamics based on the pressure from experimental measurements to reflect the internal flow characteristics for the combustion chamber and nozzle together. The grain recession calculation was carried out to obtain the grain shapes along the whole motor burning time which represents the computational domain used in simulations. The simulations will cover the whole burning time starting from ignition to tail-off obtaining all possible internal flow parameters. From these parameters, the internal ballistics of the case study DTSRM and the resulting thrust is calculated. In such cases, simulation results may be used to predict motor thrust with accuracy closer to experimental measurements compared with the analytical calculations.

II. Experimental Motor

For the present case study, a test solid rocket motor is adopted, Figure 1a with the pressure transducer adjusted at the head end of the motor. A tubular grain of two different inner diameters along the axis is used. The tubular grain is inhibited from the outer surface adjacent to the motor casing while it is allowed to burn from all other surfaces, Figure 1b. The solid propellant composition includes ammonium perchlorate, Aluminum powder, and HTPB with the percentages shown in Table 1. The burning law for the propellant is defined as:

$$r = 2.68 \times 10^{-4} p^{0.2101} \tag{1}$$



a) The test motor

b) The propellant grain (all dimensions in millimeters)

Figure 1: The experimental motor and the propellant grain

Table 1: Propellant Ingredient

	AP	Al	HTPB
Chemical formula	NH_4ClO_4	Al	$C_{7.09}H_{10.86}O_{0.227}$
Weight percentage[%]	69	17	14
Enthalpy [kcal/mol]	-70.69	0	-14.64

III. Methodology

For sake of numerical simulation, the pressure ~ time curve from experimental measurements was divided into five regimes namely, ignition transient phase, boost steady phase, transition transient phase, sustain steady phase, and tail-off transient phase as shown in Figure 2. For each of the two steady-state phases, four-time instances are investigated; one at the start, one at the end, and two in the middle of each phase. In contrast, the full duration of each of the three transient phases is examined. The grain recission is calculated at each burning step for the whole burning time to be used in simulations representing the three transient phases and the eight points of steady-state phases computational domains.

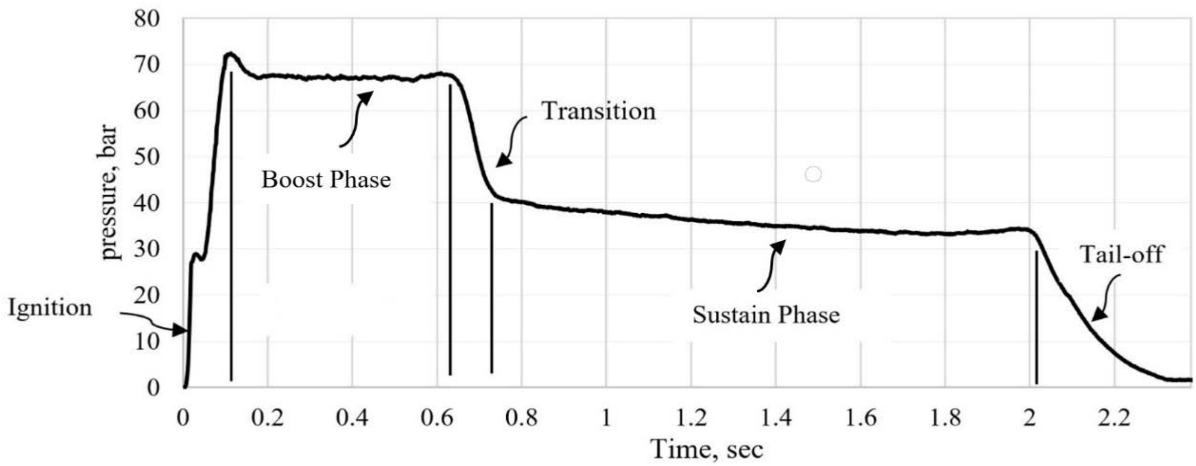


Figure 2: Pressure-time curve of the test rocket motor divided into regimes

The ignition phase represents the rise of the pressure from 0 to 71 bar in about 0.1 seconds, the boost phase of the test motor operation endures for about 0.5 seconds where pressure varies from about 71 to 68 bar. The transition represents the change from boost to sustain phase with a variation of pressure from 68 to 42 bar in 0.1 seconds. During the 1.12 seconds sustain phase, the motor pressure drops from 41 to 36 bar. Finally, the tail-off phase represents the collapse of pressure from 36 to 1 bar in about 0.33 seconds. The burning of propellant grain surfaces results in gases with direction normal to these surfaces, to simplify the problem, and as the pressure transducer is adjusted at the head end of the experimental motor, the simulation input (experimental pressure measurements) is adopted as pressure inlet.

a) Computational Domain

Due to grain regression during both boost and sustain phases, the computational domain geometry varies with time. Figure 3shows the instantaneous grain locationscalculatedusing the burning law (Equation 1) based on instantaneous chamber pressure values at five different times of burning. For more realistic simulations, the natural change of sharp corners into rounded ones upon regression is taken into consideration. The grain configuration at 0 seconds represents the computational domain for ignition phase transient simulation and boost start steady-state simulation. Grain location at 0.6 seconds represents the domain for boost-end steady-state simulation. Grain location at 0.75 seconds represents the domain for both sustain-start steady-state simulation and boost-sustain transition simulation. Grain location at 1.5 seconds is taken to define sustain-end steady-state simulation. For tail-off transient simulation, an empty chamber is considered.

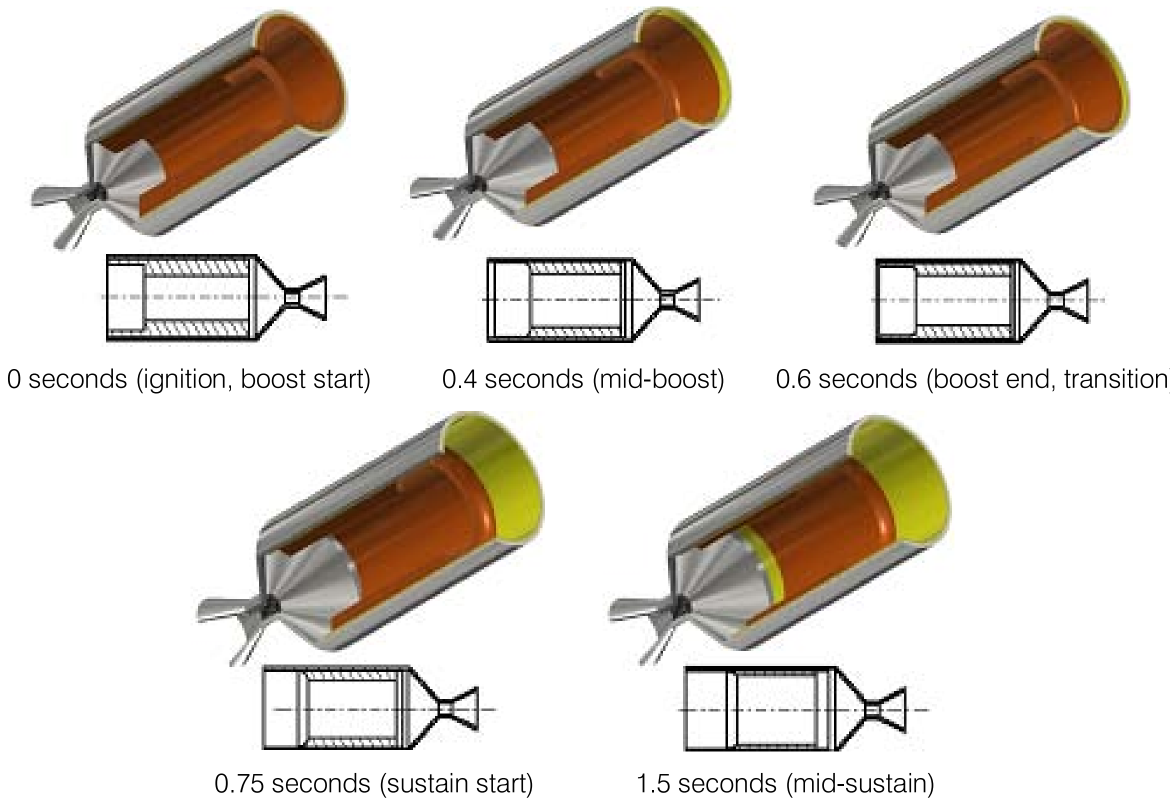


Figure 4: Grain configuration at the time instances in consideration

Due to the symmetry of flow and domain, two-dimensional axisymmetric computational domains are developed for all simulations. Multi-block structured grids are constructed such that grid quality is increased at areas of interest namely, solid walls, the nozzle critical section, and its upstream and downstream vicinity.

The mesh in the present work used structured grid element shape with appropriate number of divisions that suit each part of the motor. Spatial resolution is assessed through a grid independence check, the pressure at the throat was observed, and the grid-independent solution was obtained at 252000 cells. All wall boundaries in the domain are defined with the no-slip condition while the lower (bottom) boundary is defined as the axis. Consistent with experiments, the downstream (right) end of the domain is defined as a pressure outlet with atmospheric pressure definition. To simplify simulations, and since the pressure input to simulations is based on readings of a pressure transducer that is adjusted at the head end of the experimental motor, the upstream (left) end of the domain is defined as a pressure inlet as shown in Figure 5, which illustrate the mesh used in boost start steady case.

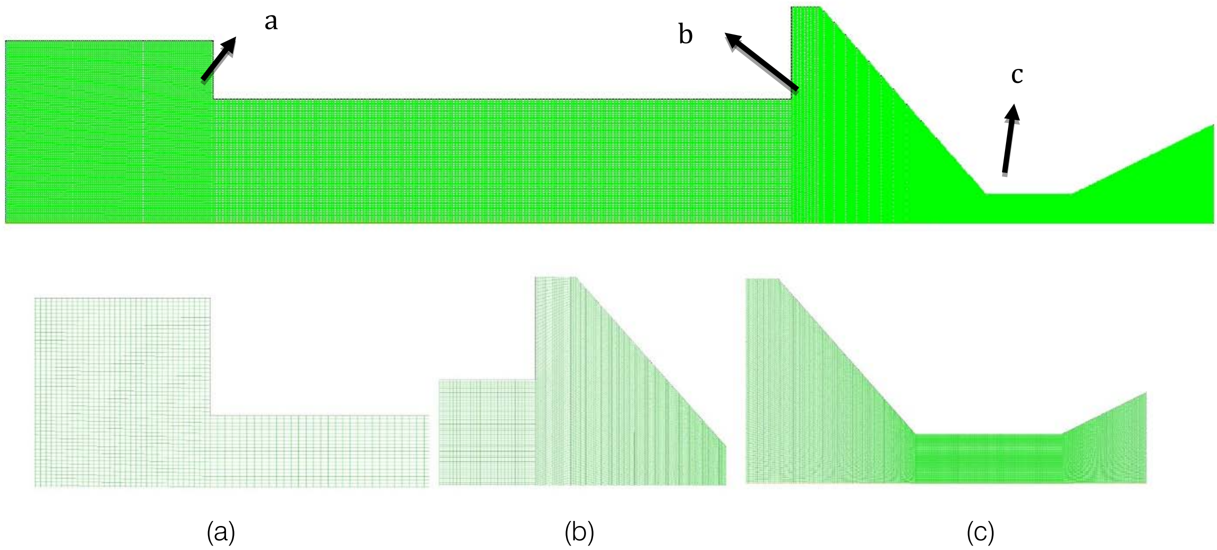


Figure 5: Mesh used in the boost start phase

b) Boundary Conditions

For the steady-state simulation, four main cases were selected to be discussed (boost-start, boost-end, sustain-start, and sustain-end), the instantaneous combustion pressures at the time instances in concern are set based on Figure 2. Hence, four steady cases correspond to inlet pressures of 71, 68, 41, and 36, respectively will be explained in detail in the current study. Another four cases are simulated, two in each steady phase to cover more points in the thrust curve and increase the prediction accuracy.

For transient phases simulations of Transition and Tail off, pressure inlet values are user-defined functions of time extracted from Fitted trendlines equations of the experimental curves illustrated in Figure 6, whereas in the ignition phase, the pressure-time relation is input as a table of discrete points (extracted from ignition experimental curve) within which instantaneous pressure value is interpolated.

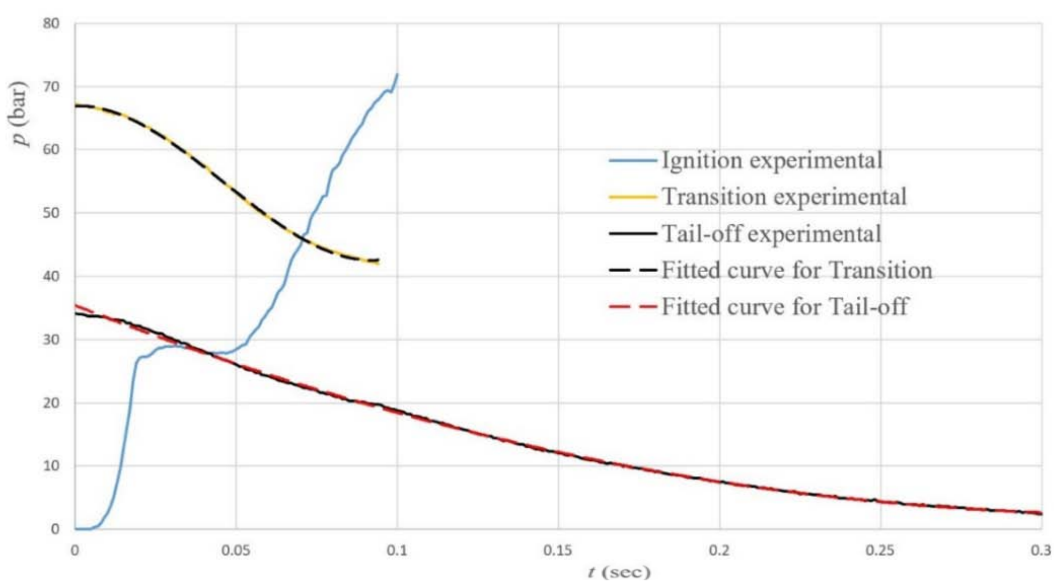


Figure 6: Temporal pressure variation of pressure inlet boundary for transient phases simulations

For boost-sustain and tail-off transient phases' simulations, the experimental pressure-time curve data is analyzed and equations of the fitted curves (polynomial equations of trendlines) are used in the user-defined function input files. These functions are:

Transition phase: $$p = 64830t^3 - 9029.6t^2 + 16.745t + 66.935 \quad (2)$$

Tail-off phase: $$p = 303.9t^2 - 200.28t + 35.408 \quad (3)$$

where p is the inlet pressure value in bar while t represents the time in seconds.

c) Operating Fluid Properties

Properties of working gas adopted in CFD solver setup are sought to be as close to real combustion as possible. This is done by conducting thermochemical calculations using NASA CEA [28] code. It is one of the thermochemical programs that are capable of calculating the chemical equilibrium compositions of a chemical system via minimization of free energy formulation, which allows one to calculate theoretical thermochemical properties. Combustion pressure is input as well as ingredients of solid propellant (listed in Table 1) as reactants in the form of weight percentage along with enthalpy, temperature, and chemical formula of each. Grain burning is considered a finite area combustion problem with a contraction ratio (ratio of finite chamber area to throat area) of 7.475 and an initial chamber temperature guess of 3800k. Table 2 lists the operating gas properties for all steady cases in boost and sustain phases.

Table 2: Operating gas properties as calculated by NASA CEA

Simulation Case Parameter	Boost start	Boost end	Sustain start	Sustain end
Camber pressure (bar)	71	68	41	36
Temperature (K)	3388	3385	3344	3332
Density (kg/m^3)	6.9038	6.6119	3.9767	3.4868
Specific heat (J/kg.K)	3547.3	3568.7	3836.2	3910.1
Thermal conductivity (w/m.K)	1.0381	1.0467	1.1554	1.1856
Viscosity (kg/m.s)	9.88 e-05	9.87e-05	9.7925e-05	9.769e-05
Specific heat ratio	1.1411	1.1409	1.1378	1.1370
Specific gas constant (J/K.mol)	323.27	323.397	324.78	325.15

d) CFD Solver Setup

The pressure-based solver for Navier-Stokes equations is adopted. For the pressure-velocity-coupling scheme, the pressure-based coupled algorithm is chosen as it gives a more efficient, accurate, and robust single-phase implementation in cases of steady-state flows. Turbulence is modeled in Reynolds-Averaged Navier-Stokes (RANS) through the standard k-ε model. It is preferred because of its reasonable accuracy and reliability for a wide range of turbulent flows and heat transfer. It is thus the most commonly used turbulence model, especially with solid rocket motors cases [29-33]. Gradients are computed in the current work using the Least-square cell-based method while the PRESTO discretization scheme is chosen as it is more suitable for multiphase simulations. For unsteady simulation cases, the time step size in each case is chosen to be compatible with the input file data based on a temporal resolution sensitivity check. The working fluid is chosen as an ideal gas with the specifications tabulated in Table 2.

IV. Discussion of Internal Ballistics Simulation Results

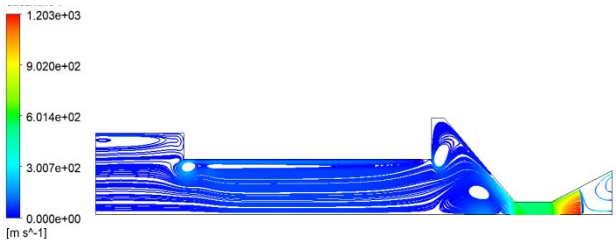
Results of numerical simulation for the flow inside the test motor in concern are discussed below in two sections, transient phases, and steady-state phases.

a) Transient Phases

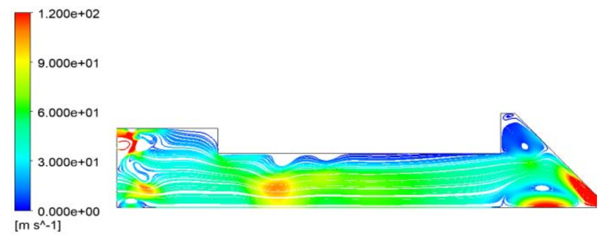
Figure 7 (a, b, c, and d) shows the flow velocity streamlines along the motor at different times of the ignition phase colored according to velocity values, Figure 6.a shows the whole motor with nozzle, whereas the other figures focus on the velocity streamlines variation inside the combustion chamber. Vortices can be noticed inside the combustion chamber at the beginning of ignition, especially in the gap between grain and nozzle. These vortices seem to diminish or vanish with time as the pressure becomes high enough to make the flow smoother. The flow parameters change along the motor at different times of ignition are shown in Figure 8 where flow pressure and velocity along the axis are displayed. Flow pressure has a high, nearly constant, value inside the combustion chamber and these values decrease along the nozzle at all times of ignition. In contrast, velocity is nearly zero inside the chamber and then increases along with the nozzle. It can be noticed that the flow doesn't fully expand along the nozzle at the beginning of ignition where the pressure value inside the combustion chamber is still not high enough.

During the transition phase, the pressure drops sharply while the grain almost maintains its configuration. The velocity streamlines variation at different times of transition phase time is shown in Figure 7 (e, f, g, and h). It can be noticed that the flow streamlines as it transfers from the boost phase with high pressure to the sustain phase with lower pressure become smoother. The recirculation bubbles along the motor diminish in number and size. The flow parameters along the motor at different times of this phase are shown in Figure 8. Pressure has a higher value inside the combustion chamber and decreases along the nozzle at all times of burning. The flow velocity inside the combustion chamber has a low value that increases along the nozzle.

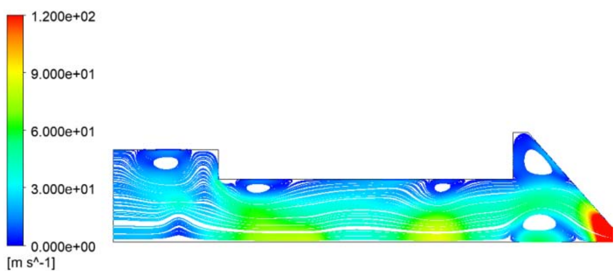
The tail-off phase represents about 0.3 seconds of motor operation. Figure 7 (i, j, k, and l) shows the variation of flow streamlines colored according to velocity values. Over time, the velocity decrease as the pressure inside the combustion chamber is relieved and the streamlines vortices still exist inside the empty motor. The flow parameters along with the motor at different times of this phase are shown in Figure 8.



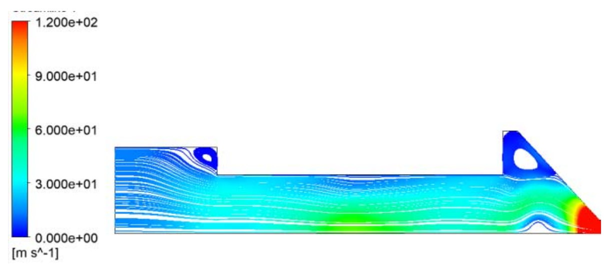
(a) 0.002 seconds of ignition



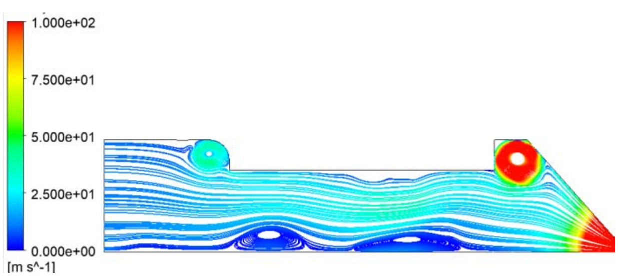
(b) 0.006 seconds of ignition



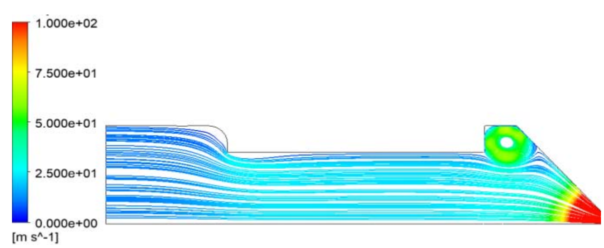
(c) 0.04 seconds of ignition



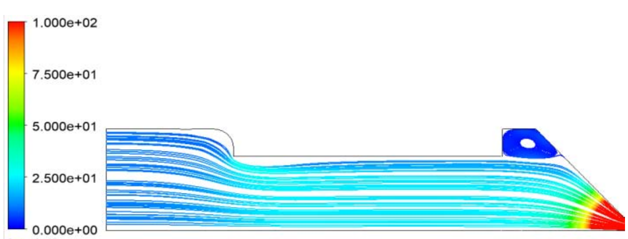
(d) 0.1 seconds of ignition



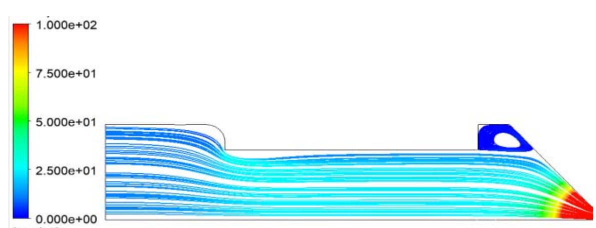
(e) 0.006 seconds of transition



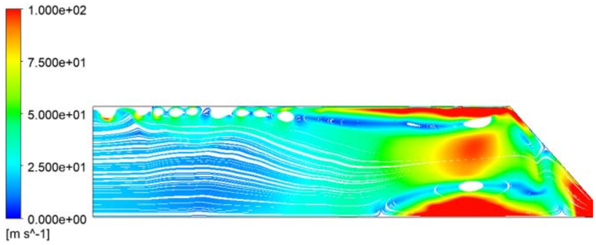
(f) 0.017 seconds of transition



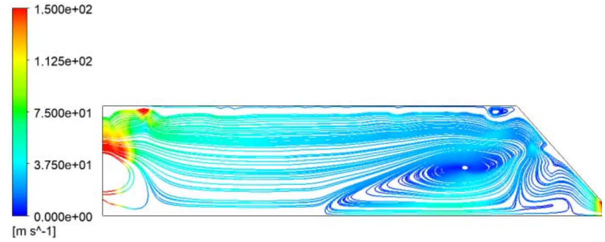
(g) 0.04 seconds of transition



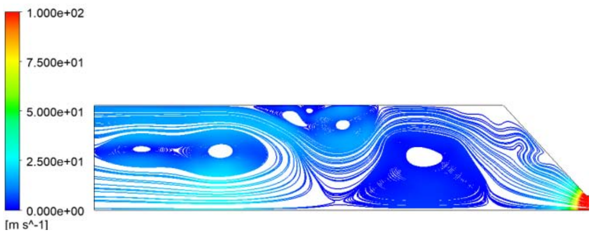
(h) 0.095 seconds of transition



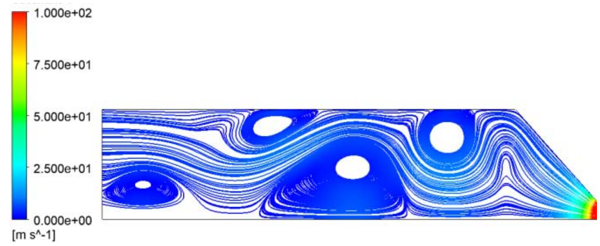
(i) 0.005 seconds of tail-off



(j) 0.02 seconds of tail-off

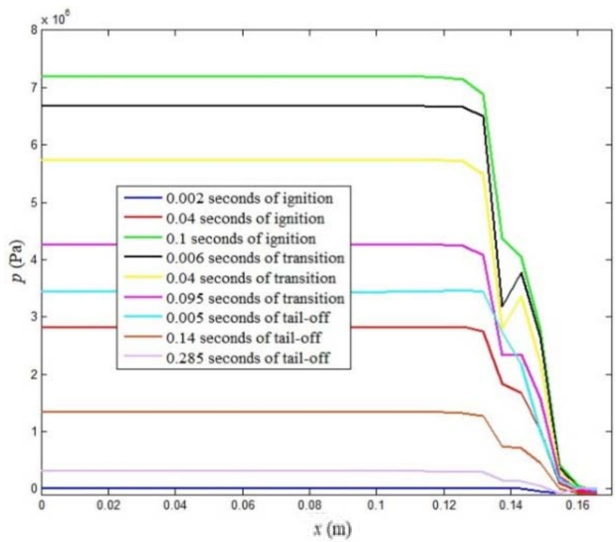


(k) 0.14 seconds of tail-off

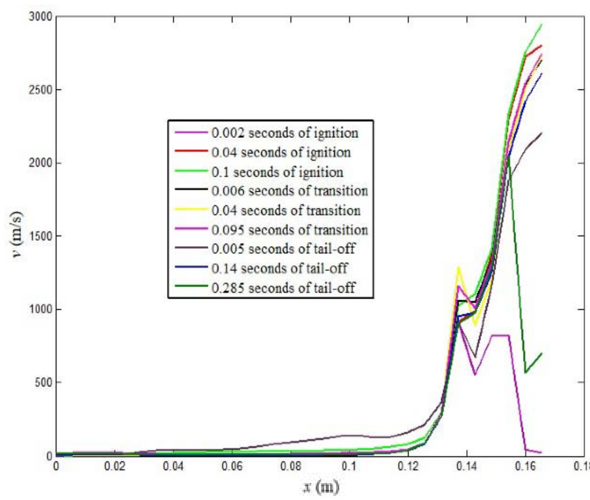


(l) 0.285 seconds of tail-off

Figure 7: Flow streamlines at different time instances during transient phases



(a) Pressure

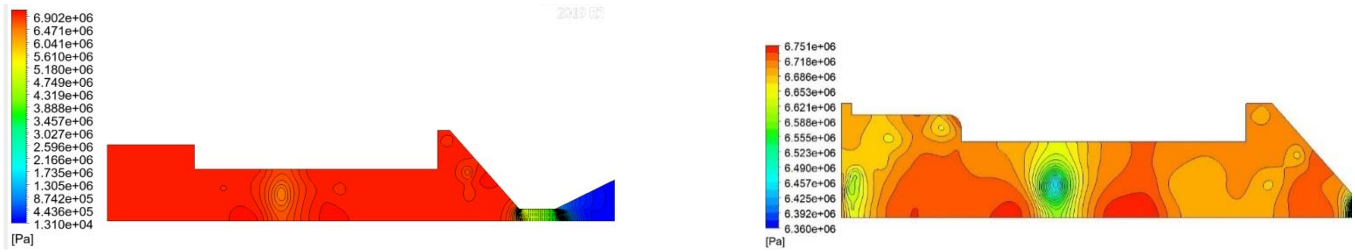


(c) Velocity

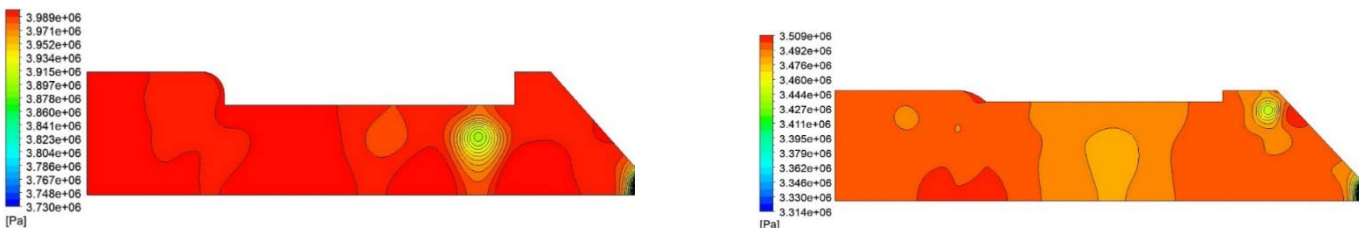
Figure 8: Variation of Pressure (left side) and Velocity (right side) along the motor axis at different times of the transient phases

b) Steady State Cases

Four steady-state simulation cases are considered for each phase, the simulation results are presented in detail for two cases at each phase namely; at its start and end. Figure 9 illustrates pressure contours along with the motor for two cases in the boost phase and two cases in the sustain phase. The first case includes the whole motor, while the other three cases focus on the combustion chamber as the pressure values are higher inside it. The pressure clouds concentrate in the middle of the motor and close to the convergent part, the pressure values are higher in the center of these clouds. In addition, the variation of gases pressure and Mach Number along the motor axis at the start and end of each steady phase is illustrated in Figure 10.



(a) Boost start (b) Boost end



(c) Sustain start (d) Sustain end

Figure 9: Pressure contours at the start and end of each steady phase

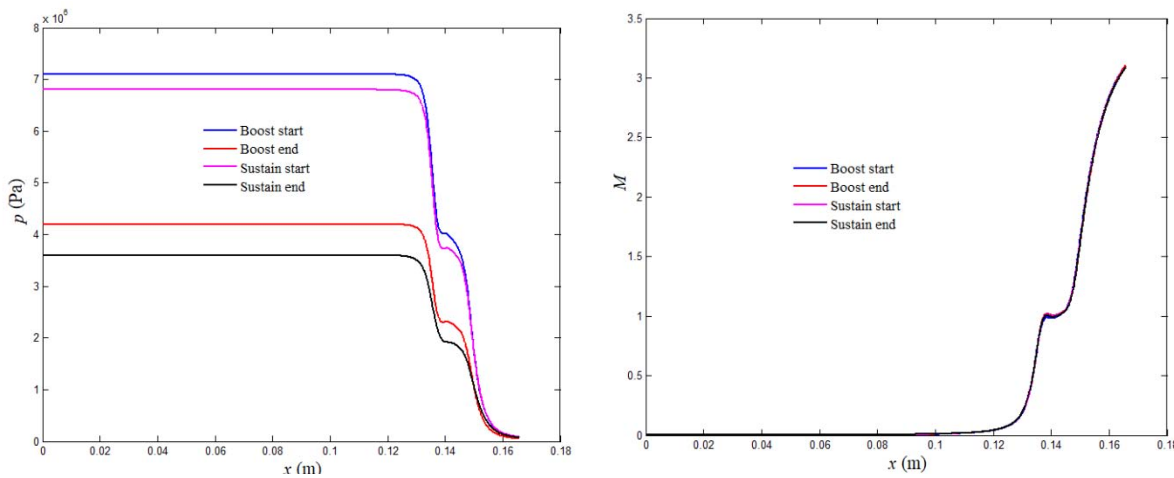


Figure 10: Variation of Pressure (left side) and Mach Number (right side) along the motor axis at the start and end of each steady phase

The pressure at the combustion chamber is high and starts to decrease once it enters the nozzle and continues decreasing as the flow passes through the nozzle divergent section until it reaches the atmospheric value at exit. In contrast, the Mach number starts to rise above zero at the nozzle inlet, reaches the value of one at the nozzle throat, and above 3 at the nozzle exit. Flow properties vary in the radial direction as well. Figure 11 shows the variation of flow pressure and Mach number with radius along the nozzle exit. While pressure reaches a maximum value midway along the nozzle radius in boost phase cases, it reaches a maximum value near the walls in sustain phase cases. Mach value drops sharply inside the boundary layer over the wall, for the boost phase cases it decreases to 2 while for the sustain phases it reaches 0.5.

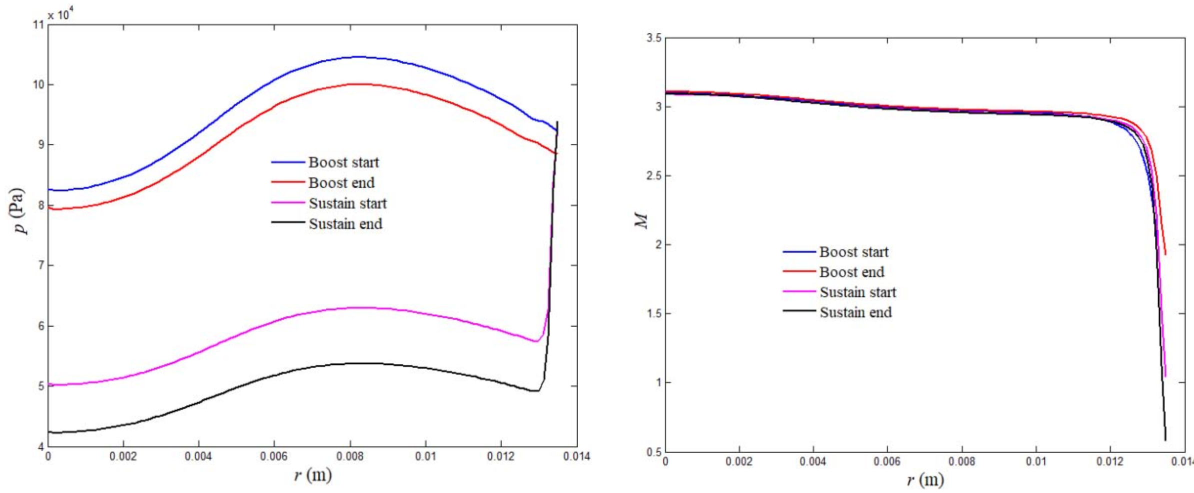


Figure 11: Variation of Pressure (left side) and Mach Number (right side) along the motor exit

V. Validation of Thrust Calculation

An analytical model was developed based on dividing the web thickness into segments, a solution of the governing equation for each segment is performed, and a comparison is made to check whether the total mass generated from grain burning equals the total mass discharged from the nozzle [34]. The model was adopted to calculate the thrust for the used motor. The root mean square error between analytical calculations and experimental measurements is about 15% as shown in Figure 12. The error was estimated based on the difference between the thrust values calculated analytically and experimentally measured. The root mean square of the difference is the error represented in the current method.

The thrust based on the numerical simulation is calculated using the flow properties calculated at the exit section of the nozzle via the following equation [35]:

$$F = \dot{m}\, V_e + A_e (P_e - P_a) \quad (4)$$

where $\dot{m}$ is the mass flow rate discharged from the motor nozzle exit, V_e is the average velocity inthis area, A_e is the surface area of the exit section, P_e is the average exit pressure, and P_a is the atmospheric pressure (101325 Pascal). The calculated values of these parameters for the four steady-state cases examined here are listed in Table 3, beside the main four points, two in each phase to cover the curve. The thrust values calculated using the numerical simulation are compared with thrust experimental measurements, Figure 12.

Table 3: Numerical parameters used in thrust calculations for main steady phases

	Boost-start	Boost-end	Sustain-start	Sustain-end
Mass flow rate (kg/sec)	0.1896	0.18095	0.1114	0.09799
Exit pressure (Pascal)	95734.06	90775.95	57962.66	50508.6
Exit velocity (m/sec)	2806	2804	2806	2804

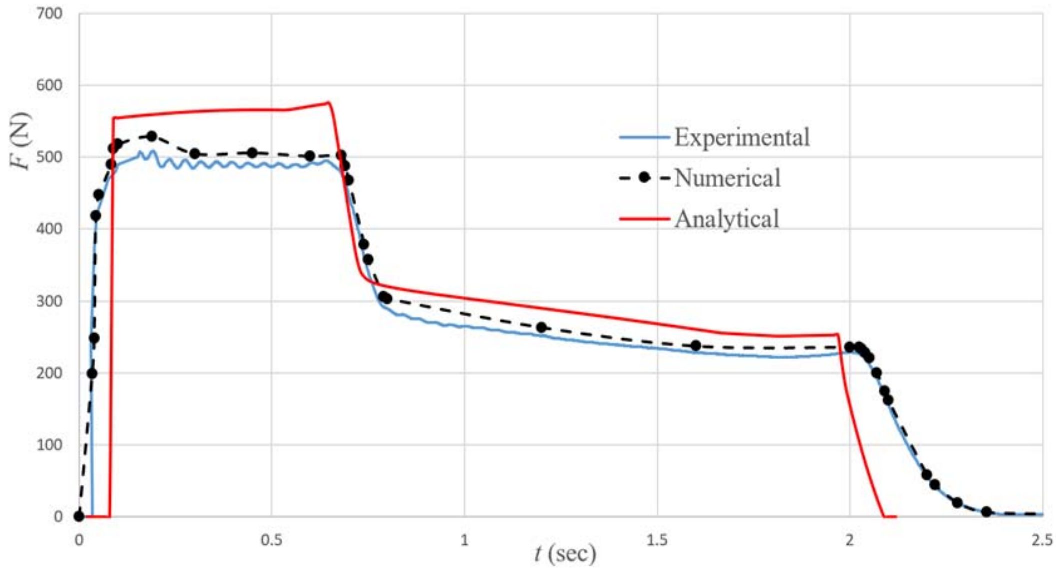


Figure 12: Experimental vs Numerical and Analytical thrust ~ time curves

The numerical simulation values are in a marginal similarity to measured values with a relative error of less than 5% whereas the analytical calculation can predict the thrust with an accuracy of about 15% relative to the experimental measurements. The deviation between the numerical simulation and the experimental measurements in the transient phases is less than the deviation in the boost and sustain phase, this is due to the relative error occurring during burnback calculation analysis in the boost and sustain phase, but in the transient phases, the grain burn back process doesn't exist. It can be concluded from this comparison that numerical simulations are capable of calculating thrust using measured pressure as an alternative to thrust measurements.

VI. Conclusion

An experiment-based numerical simulation and analysis for a dual thrust solid-propellant motor was carried out to investigate the flow features and parameters along the motor and nozzle for the whole working time. This gives more understanding and better insight that cannot be accomplished with experimental measurements. The pressure-time curve from experimental measurements was analyzed to obtain the inputs required for the simulations whereas gas parameters were calculated from thermochemical calculations. The pressure-time curve was divided into two types of simulation, steady-state and transient, the steady-state phase was represented in two phases, boost phase and sustain phase steady-state simulations. The transient phases were represented in three phases, ignition phase, transition (from boost to sustain) phase, and tail off phase. The results from numerical simulation were used to calculate the motor thrust via using the parameters marched out from the motor exit. The thrust values calculated from numerical simulations were compared with the experimental measurements and the error was less than 5% in all cases. Numerical simulations were confirmed capable of explaining the flow parameters variations with time as well as calculating the motor thrust with a remarkable level of accuracy compared with analytical calculations that are more suited for preliminary calculations.

References Références Referencias

1. Blazek J. Flow simulation in solid rocket motors using advanced CFD. 39th AIAA/ASME/SAE/ASEE Joint Propulsion Conference and Exhibit. 2003; 5111.
2. Hartfield RJ, DiMaggio GA, Majdalani J. Efficient Solution Approach for Internal Ballistics. AIAA Propulsion and Energy 2020 Forum. 2020; 3926.
3. Ramesh Kumar R, Devarajan Y. CFD simulation analysis of two-dimensional convergent-divergent nozzle. International Journal of Ambient Energy 2020; 41(13):1505-15.
4. Najar NA, Dandotiya D, Najar FA. Comparative analysis of k-ε and spalart-allmaras turbulence models for compressible flow through a convergent-divergent nozzle. The International Journal of Engineering Science 2013; 2(8):8-17.
5. Tanveer N, Mohanraj C, Jegadeesan K, Maruthupandiyan S. Comparative studies on various turbulent models with liquid rocket nozzle through computational tool. Advanced Materials Research. 2014; 1204-9.
6. Kostić O, Stefanović Z, Kostić I. CFD modeling of supersonic airflow generated by 2D nozzle with and without an obstacle at the exit section. FME Transactions 2015; 43(2):107-13.

7. Dang Le Q, Mereu R, Besagni G, Dossena V, Inzoli F. Computational fluid dynamics modeling of flashing flow in convergent-divergent nozzle. Journal of Fluids Engineering 2018; 140(10):1-22.
8. Natta P, Kumar VR, Rao YH. Flow analysis of rocket nozzle using computational fluid dynamics (CFD). International Journal of Engineering Research Applications 2012; 2(5):468-71.
9. Ajith S, Nichith C, Vignesh S, et al. 3D Flame Spread and Starting Transient in Dual-thrust Solid Propellant Rocket Motors. 52nd AIAA/SAE/ASEE Joint Propulsion Conference. 2016; 4598.
10. Sanal Kumar V, Ramesh kumar T, John J, Basavanahalli R. 3D Flow Simulation of Dual Thrust Solid Rocket Motors during Starting Transient. 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. 2014; 3807.
11. Chandrasekaran N, Sankar V, Nejaamtheen MN, Selvakumar K, Rahman SA, Sanal Kumar V. Analytical and Numerical Predictions of Boundary Layer Blockage in Dual Thrust Motors. 2018 Joint Propulsion Conference. 2018; 4880.
12. Ajith S, Mani S, Tharikaa R, Nagaraju Doddi H, Sanal Kumar V. Diagnostic investigation of flame spread mechanism in dual-thrust solid propellant rocket motors. 51st AIAA/SAE/ASEE Joint Propulsion Conference. 2015; 4226.
13. Chandrasekaran N, Sankar V, Padmanabhan S, et al. Studies on Oscillating Boundarylayer During the Ignition Transient of Dual-thrust Solid Rocket Motors. 53rd AIAA/SAE/ASEE Joint Propulsion Conference. 2017; 4691.
14. Cho IH, Baek SW. Numerical simulation of axisymmetric solid rocket motor ignition transient with radiation effect. Journal of Propulsion and Power 2000; 16(4):725-8.
15. Ropia B, Shekhar HK, Thakur DG. Study of Initial Pressure Rise in Multi Grain Solid Propellant Rocket Motor. Propellants, Explosives, Pyrotechnics 2020; 45(5):741-50.
16. Bianchi D, Grossi M, Favini B, Serraglia F, Ierardo N. Analysis and Reconstruction of Zefiro 40 Solid Rocket Motor Static Firing Tests and Extrapolation to Flight. AIAA Propulsion and Energy 2021 Forum. 2021; 3703.
17. Tengli PN, Ramesh C, Viswanathan K, Saravanan. Vortex flow analysis of a large segmented solid rocket motor. Indian Journal of Science and Technology 2012; 5(1):1888-92.
18. Chen L, Gao Y, Wang D, Zou Q, Zhang S. Numerical simulation on acoustic mode and pressure-oscillation decay in finocyl-and axil-grain combustion chambers. Aerospace Science and Technology 2020; 107:106351.
19. French AD, Panelli M, Di Lorenzo G, Schettino A, Paglia F. Combustion instability and Pressure oscillation numerical simulation in a solid rocket motor. 53rd AIAA/SAE/ASEE Joint Propulsion Conference. 2017; 4952.
20. Ji S, Wang B, Zhao D. Numerical analysis on combustion instabilities in end-burning-grain solid rocket motors utilizing pressure-coupled response functions. Aerospace Science and Technology 2020; 98:105701.
21. Di Mascio A, Cavallini E, Favini B, Neri A. Numerical Simulation of 3D Unsteady Flowfield in Aft-Finocyl Solid Rocket Motor. 50th AIAA/ASME/SAE/ASEE Joint Propulsion Conference. 2014; 4015.
22. Pengfei R, Hongbo W, Guofeng Z, et al. Solid rocket motor propellant grain burnback simulation based on fast minimum distance function calculation and improved marching tetrahedron method. Chinese Journal of Aeronautics 2021; 34(4):208-24.
23. Li Q, He G-q, Liu P-j, Li J. Coupled simulation of fluid flow and propellant burning surface regression in a solid rocket motor. Computers and Fluids 2014; 93:146-52.
24. Qingyu L, Kun J, Hao W, Jinlong W. Application of immersed boundary method to the simulation of transient flow in solid rocket motors. Aerospace Science and Technology 2021; 1.310:1-14.
25. Zou X, Wang N, Han L, Bai T, Xie K. Numerical investigation on regression rate and thrust regulation behaviors of a combined solid rocket motor with aluminum-based fuel. Aerospace Science and Technology 2021; 119:107102.
26. Han S, Kim C. Integrated Fluid–Structure Simulation for Full Burning of a Solid-Propellant Rocket Interior. Journal of Propulsion and Power 2014; 30(4):883-900.
27. Hemanth VA, Jyothi U. CFD Analysis of a Solid Propellant Retro Rocket Motor using Ansys Fluent. International Conference on Design and Manufacturing aspects for Sustainable Energy. 2020; 01054.
28. McBride BJ. NASA Glenn coefficients for calculating thermodynamic properties of individual species: National Aeronautics and Space Administration, John H. Glenn Research Center at Lewis Field, 2002.
29. Biju Kuttan P, Sajesh M. Optimization of divergent angle of a rocket engine nozzle using computational fluid dynamics. The International Journal Of Engineering And Science 2013; 2(2):196-207.
30. Thakre P, Rawat R, Clayton R, Yang V. Mechanical erosion of graphite nozzle in solid-propellant rocket motor. Journal of Propulsion and Power 2013; 29(3):593-601.
31. Yumuşak M. Analysis and design optimization of solid rocket motors in viscous flows. 21st AIAA Computational Fluid Dynamics Conference 2013; 75:22-34.
32. Li Z, Xiang H, Zhang JT. Numerical simulation of composite solid propellant rocket motor exhaust

plume. Journal of Solid Rocket Technology 2014; 37(1):37-42.
33. Belega B-A, Nguyen TD. Analysis of flow in convergent-divergent rocket engine nozzle using computational fluid dynamics. International Conference of Scientific Paper. 2015.
34. Gawad ARA, Mohamed MY, Abdalla HM, Elsenbawi MA. Analytical Prediction of Dual-Thrust Rocket motors under Uncertainties. 16th International Conference on Aerospace Sciences & Aviation Technology , ASAT - 16 2015.
35. Sutton GP, Biblarz O. Rocket propulsion elements: John Wiley & Sons, 2016.

Global Journals Guidelines Handbook 2023

www.GlobalJournals.org

Memberships

FELLOWS/ASSOCIATES OF ENGINEERING RESEARCH COUNCIL

FERC/AERC MEMBERSHIPS

Introduction

FERC/AERC is the most prestigious membership of Global Journals accredited by Open Association of Research Society, U.S.A (OARS). The credentials of Fellow and Associate designations signify that the researcher has gained the knowledge of the fundamental and high-level concepts, and is a subject matter expert, proficient in an expertise course covering the professional code of conduct, and follows recognized standards of practice. The credentials are designated only to the researchers, scientists, and professionals that have been selected by a rigorous process by our Editorial Board and Management Board.

Associates of FERC/AERC are scientists and researchers from around the world are working on projects/researches that have huge potentials. Members support Global Journals' mission to advance technology for humanity and the profession.

FERC

FELLOW OF ENGINEERING RESEARCH COUNCIL

FELLOW OF ENGINEERING RESEARCH COUNCIL is the most prestigious membership of Global Journals. It is an award and membership granted to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Fellows are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Fellow Members.

Benefit

To the institution

Get letter of appreciation

Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

Exclusive Network

Get access to a closed network

A FERC member gets access to a closed network of Tier 1 researchers and scientists with direct communication channel through our website. Fellows can reach out to other members or researchers directly. They should also be open to reaching out by other.

Career | Credibility | Exclusive | Reputation

Certificate

Certificate, LoR and Laser-Momento

Fellows receive a printed copy of a certificate signed by our Chief Author that may be used for academic purposes and a personal recommendation letter to the dean of member's university.

Career | Credibility | Exclusive | Reputation

Designation

Get honored title of membership

Fellows can use the honored title of membership. The “FERC” is an honored title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., FERC or William Walldroff, M.S., FERC.

Career | Credibility | Exclusive | Reputation

Recognition on the Platform

Better visibility and citation

All the Fellow members of FERC get a badge of "Leading Member of Global Journals" on the Research Community that distinguishes them from others. Additionally, the profile is also partially maintained by our team for better visibility and citation. All fellows get a dedicated page on the website with their biography.

Career | Credibility | Reputation

Future Work

Get discounts on the future publications

Fellows receive discounts on the future publications with Global Journals up to 60%. Through our recommendation programs, members also receive discounts on publications made with OARS affiliated organizations.

Career Financial

GJ Account

Unlimited forward of Emails

Fellows get secure and fast GJ work emails with unlimited storage of emails that they may use them as their primary email. For example, john [AT] globaljournals [DOT] org.

Career Credibility Reputation

Premium Tools

Access to all the premium tools

To take future researches to the zenith, fellows receive access to all the premium tools that Global Journals have to offer along with the partnership with some of the best marketing leading tools out there.

Financial

Conferences & Events

Organize seminar/conference

Fellows are authorized to organize symposium/seminar/conference on behalf of Global Journal Incorporation (USA). They can also participate in the same organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent. Additionally, they get free research conferences (and others) alerts.

Career Credibility Financial

Early Invitations

Early invitations to all the symposiums, seminars, conferences

All fellows receive the early invitations to all the symposiums, seminars, conferences and webinars hosted by Global Journals in their subject.

Exclusive

Publishing Articles & Books

Earn 60% of sales proceeds

Fellows can publish articles (limited) without any fees. Also, they can earn up to 70% of sales proceeds from the sale of reference/review books/literature/publishing of research paper. The FERC member can decide its price and we can help in making the right decision.

Exclusive Financial

Reviewers

Get a remuneration of 15% of author fees

Fellow members are eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get a remuneration of 15% of author fees, taken from the author of a respective paper.

Financial

Access to Editorial Board

Become a member of the Editorial Board

Fellows may join as a member of the Editorial Board of Global Journals Incorporation (USA) after successful completion of three years as Fellow and as Peer Reviewer. Additionally, Fellows get a chance to nominate other members for Editorial Board.

Career Credibility Exclusive Reputation

And Much More

Get access to scientific museums and observatories across the globe

All members get access to 5 selected scientific museums and observatories across the globe. All researches published with Global Journals will be kept under deep archival facilities across regions for future protections and disaster recovery. They get 10 GB free secure cloud access for storing research files.

ASSOCIATE OF ENGINEERING RESEARCH COUNCIL

ASSOCIATE OF ENGINEERING RESEARCH COUNCIL is the membership of Global Journals awarded to individuals that the Open Association of Research Society judges to have made a 'substantial contribution to the improvement of computer science, technology, and electronics engineering.

> The primary objective is to recognize the leaders in research and scientific fields of the current era with a global perspective and to create a channel between them and other researchers for better exposure and knowledge sharing. Members are most eminent scientists, engineers, and technologists from all across the world. Associate membership can later be promoted to Fellow Membership. Associates are elected for life through a peer review process on the basis of excellence in the respective domain. There is no limit on the number of new nominations made in any year. Each year, the Open Association of Research Society elect up to 12 new Associate Members.

Benefit

To the Institution

Get Letter of Appreciation

Global Journals sends a letter of appreciation of author to the Dean or CEO of the University or Company of which author is a part, signed by editor in chief or chief author.

Exclusive Network

Get access to a closed network

A AERC member gets access to a closed network of Tier 1 researchers and scientists with direct communication channel through our website. Associates can reach out to other members or researchers directly. They should also be open to reaching out by other.

Career | Credibility | Exclusive | Reputation

Certificate

Certificate, LoR and Laser-Momento

Associates receive a printed copy of a certificate signed by our Chief Author that may be used for academic purposes and a personal recommendation letter to the dean of member's university.

Career | Credibility | Exclusive | Reputation

Designation

Get honored title of membership

Associates can use the honored title of membership. The “AERC” is an honored title which is accorded to a person’s name viz. Dr. John E. Hall, Ph.D., AERC or William Walldroff, M.S., AERC.

Career | Credibility | Exclusive | Reputation

Recognition on the Platform

Better visibility and citation

All the Associate members of AERC get a badge of "Leading Member of Global Journals" on the Research Community that distinguishes them from others. Additionally, the profile is also partially maintained by our team for better visibility and citation. All associates get a dedicated page on the website with their biography.

Career | Credibility | Reputation

Future Work

Get discounts on the future publications

Associates receive discounts on the future publications with Global Journals up to 60%. Through our recommendation programs, members also receive discounts on publications made with OARS affiliated organizations.

Career Financial

GJ Account

Unlimited forward of Emails

Associates get secure and fast GJ work emails with unlimited storage of emails that they may use them as their primary email. For example, john [AT] globaljournals [DOT] org..

Career Credibility Reputation

Premium Tools

Access to all the premium tools

To take future researches to the zenith, associates receive access to all the premium tools that Global Journals have to offer along with the partnership with some of the best marketing leading tools out there.

Financial

Conferences & Events

Organize seminar/conference

Associates are authorized to organize symposium/seminar/conference on behalf of Global Journal Incorporation (USA). They can also participate in the same organized by another institution as representative of Global Journal. In both the cases, it is mandatory for him to discuss with us and obtain our consent. Additionally, they get free research conferences (and others) alerts.

Career Credibility Financial

Early Invitations

Early invitations to all the symposiums, seminars, conferences

All associates receive the early invitations to all the symposiums, seminars, conferences and webinars hosted by Global Journals in their subject.

Exclusive

Publishing Articles & Books

Earn 30-40% of sales proceeds

Associates can publish articles (limited) without any fees. Also, they can earn up to 30-40% of sales proceeds from the sale of reference/review books/literature/publishing of research paper.

Exclusive Financial

Reviewers

Get a remuneration of 15% of author fees

Associate members are eligible to join as a paid peer reviewer at Global Journals Incorporation (USA) and can get a remuneration of 15% of author fees, taken from the author of a respective paper.

Financial

And Much More

Get access to scientific museums and observatories across the globe

All members get access to 2 selected scientific museums and observatories across the globe. All researches published with Global Journals will be kept under deep archival facilities across regions for future protections and disaster recovery. They get 5 GB free secure cloud access for storing research files.

Associate	Fellow	Research Group	Basic
$4800 **lifetime designation**	$6800 **lifetime designation**	$12500.00 **organizational**	APC **per article**
Certificate, LoR and Momento 2 discounted publishing/year **Gradation** of Research 10 research contacts/day **1 GB** Cloud Storage **GJ** Community Access	**Certificate,** LoR and Momento **Unlimited** discounted publishing/year **Gradation** of Research **Unlimited** research contacts/day **5 GB** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**Certificates,** LoRs and Momentos **Unlimited** free publishing/year **Gradation** of Research **Unlimited** research contacts/day **Unlimited** Cloud Storage **Online Presense** Assistance **GJ** Community Access	**GJ** Community Access

We accept the manuscript submissions in any standard (generic) format.

We typeset manuscripts using advanced typesetting tools like Adobe In Design, CorelDraw, TeXnicCenter, and TeXStudio. We usually recommend authors submit their research using any standard format they are comfortable with, and let Global Journals do the rest.

Alternatively, you can download our basic template from https://globaljournals.org/Template.zip

Authors should submit their complete paper/article, including text illustrations, graphics, conclusions, artwork, and tables. Authors who are not able to submit manuscript using the form above can email the manuscript department at submit@globaljournals.org or get in touch with chiefeditor@globaljournals.org if they wish to send the abstract before submission.

Before and during Submission

Authors must ensure the information provided during the submission of a paper is authentic. Please go through the following checklist before submitting:

1. Authors must go through the complete author guideline and understand and *agree to Global Journals' ethics and code of conduct,* along with author responsibilities.
2. Authors must accept the privacy policy, terms, and conditions of Global Journals.
3. Ensure corresponding author's email address and postal address are accurate and reachable.
4. Manuscript to be submitted must include keywords, an abstract, a paper title, co-author(s') names and details (email address, name, phone number, and institution), figures and illustrations in vector format including appropriate captions, tables, including titles and footnotes, a conclusion, results, acknowledgments and references.
5. Authors should submit paper in a ZIP archive if any supplementary files are required along with the paper.
6. Proper permissions must be acquired for the use of any copyrighted material.
7. Manuscript submitted *must not have been submitted or published elsewhere* and all authors must be aware of the submission.

Declaration of Conflicts of Interest

It is required for authors to declare all financial, institutional, and personal relationships with other individuals and organizations that could influence (bias) their research.

Policy on Plagiarism

Plagiarism is not acceptable in Global Journals submissions at all.

Plagiarized content will not be considered for publication. We reserve the right to inform authors' institutions about plagiarism detected either before or after publication. If plagiarism is identified, we will follow COPE guidelines:

Authors are solely responsible for all the plagiarism that is found. The author must not fabricate, falsify or plagiarize existing research data. The following, if copied, will be considered plagiarism:

- Words (language)
- Ideas
- Findings
- Writings
- Diagrams
- Graphs
- Illustrations
- Lectures

- Printed material
- Graphic representations
- Computer programs
- Electronic material
- Any other original work

Authorship Policies

Global Journals follows the definition of authorship set up by the Open Association of Research Society, USA. According to its guidelines, authorship criteria must be based on:

1. Substantial contributions to the conception and acquisition of data, analysis, and interpretation of findings.
2. Drafting the paper and revising it critically regarding important academic content.
3. Final approval of the version of the paper to be published.

Changes in Authorship

The corresponding author should mention the name and complete details of all co-authors during submission and in manuscript. We support addition, rearrangement, manipulation, and deletions in authors list till the early view publication of the journal. We expect that corresponding author will notify all co-authors of submission. We follow COPE guidelines for changes in authorship.

Copyright

During submission of the manuscript, the author is confirming an exclusive license agreement with Global Journals which gives Global Journals the authority to reproduce, reuse, and republish authors' research. We also believe in flexible copyright terms where copyright may remain with authors/employers/institutions as well. Contact your editor after acceptance to choose your copyright policy. You may follow this form for copyright transfers.

Appealing Decisions

Unless specified in the notification, the Editorial Board's decision on publication of the paper is final and cannot be appealed before making the major change in the manuscript.

Acknowledgments

Contributors to the research other than authors credited should be mentioned in Acknowledgments. The source of funding for the research can be included. Suppliers of resources may be mentioned along with their addresses.

Declaration of funding sources

Global Journals is in partnership with various universities, laboratories, and other institutions worldwide in the research domain. Authors are requested to disclose their source of funding during every stage of their research, such as making analysis, performing laboratory operations, computing data, and using institutional resources, from writing an article to its submission. This will also help authors to get reimbursements by requesting an open access publication letter from Global Journals and submitting to the respective funding source.

Preparing your Manuscript

Authors can submit papers and articles in an acceptable file format: MS Word (doc, docx), LaTeX (.tex, .zip or .rar including all of your files), Adobe PDF (.pdf), rich text format (.rtf), simple text document (.txt), Open Document Text (.odt), and Apple Pages (.pages). Our professional layout editors will format the entire paper according to our official guidelines. This is one of the highlights of publishing with Global Journals—authors should not be concerned about the formatting of their paper. Global Journals accepts articles and manuscripts in every major language, be it Spanish, Chinese, Japanese, Portuguese, Russian, French, German, Dutch, Italian, Greek, or any other national language, but the title, subtitle, and abstract should be in English. This will facilitate indexing and the pre-peer review process.

The following is the official style and template developed for publication of a research paper. Authors are not required to follow this style during the submission of the paper. It is just for reference purposes.

Manuscript Style Instruction (Optional)

- Microsoft Word Document Setting Instructions.
- Font type of all text should be Swis721 Lt BT.
- Page size: 8.27" x 11'", left margin: 0.65, right margin: 0.65, bottom margin: 0.75.
- Paper title should be in one column of font size 24.
- Author name in font size of 11 in one column.
- Abstract: font size 9 with the word "Abstract" in bold italics.
- Main text: font size 10 with two justified columns.
- Two columns with equal column width of 3.38 and spacing of 0.2.
- First character must be three lines drop-capped.
- The paragraph before spacing of 1 pt and after of 0 pt.
- Line spacing of 1 pt.
- Large images must be in one column.
- The names of first main headings (Heading 1) must be in Roman font, capital letters, and font size of 10.
- The names of second main headings (Heading 2) must not include numbers and must be in italics with a font size of 10.

Structure and Format of Manuscript

The recommended size of an original research paper is under 15,000 words and review papers under 7,000 words. Research articles should be less than 10,000 words. Research papers are usually longer than review papers. Review papers are reports of significant research (typically less than 7,000 words, including tables, figures, and references)

A research paper must include:

a) A title which should be relevant to the theme of the paper.
b) A summary, known as an abstract (less than 150 words), containing the major results and conclusions.
c) Up to 10 keywords that precisely identify the paper's subject, purpose, and focus.
d) An introduction, giving fundamental background objectives.
e) Resources and techniques with sufficient complete experimental details (wherever possible by reference) to permit repetition, sources of information must be given, and numerical methods must be specified by reference.
f) Results which should be presented concisely by well-designed tables and figures.
g) Suitable statistical data should also be given.
h) All data must have been gathered with attention to numerical detail in the planning stage.

Design has been recognized to be essential to experiments for a considerable time, and the editor has decided that any paper that appears not to have adequate numerical treatments of the data will be returned unrefereed.

i) Discussion should cover implications and consequences and not just recapitulate the results; conclusions should also be summarized.
j) There should be brief acknowledgments.
k) There ought to be references in the conventional format. Global Journals recommends APA format.

Authors should carefully consider the preparation of papers to ensure that they communicate effectively. Papers are much more likely to be accepted if they are carefully designed and laid out, contain few or no errors, are summarizing, and follow instructions. They will also be published with much fewer delays than those that require much technical and editorial correction.

The Editorial Board reserves the right to make literary corrections and suggestions to improve brevity.

Format Structure

It is necessary that authors take care in submitting a manuscript that is written in simple language and adheres to published guidelines.

All manuscripts submitted to Global Journals should include:

Title

The title page must carry an informative title that reflects the content, a running title (less than 45 characters together with spaces), names of the authors and co-authors, and the place(s) where the work was carried out.

Author details

The full postal address of any related author(s) must be specified.

Abstract

The abstract is the foundation of the research paper. It should be clear and concise and must contain the objective of the paper and inferences drawn. It is advised to not include big mathematical equations or complicated jargon.

Many researchers searching for information online will use search engines such as Google, Yahoo or others. By optimizing your paper for search engines, you will amplify the chance of someone finding it. In turn, this will make it more likely to be viewed and cited in further works. Global Journals has compiled these guidelines to facilitate you to maximize the web-friendliness of the most public part of your paper.

Keywords

A major lynchpin of research work for the writing of research papers is the keyword search, which one will employ to find both library and internet resources. Up to eleven keywords or very brief phrases have to be given to help data retrieval, mining, and indexing.

One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

Preparation of Eletronic Figures for Publication

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

Tips for Writing a Good Quality Engineering Research Paper

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

The Administration Rules

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation)
by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

Index

save our planet

Global Journal of Researches in Engineering

Visit us on the Web at www.GlobalJournals.org | www.EngineeringResearch.org
or email us at helpdesk@globaljournals.org

ISSN 9755861