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Research Article



# The VRMAMIK conjecture: observations and mechanisms


## Abstract

The current study aims to systematically conduct lab-scale experiments to gain a fundamental understanding of controlling mechanism. This work involves investigations on combustion behavior in presence of coupled external heat sources as well as heat sinks under varying conditions of, linear and non-linear spatial configurations, temporal/unsteady analysis of energy transfer prediction, for varying surface orientations(s) and arrays configurations. Different configurations of external heat sources and heat sinks were experimented with under diverse conditions and changes in the pilot fuel combustion rates were systematically assessed. The combustion characteristics viz., flame spread rates, flame structure, and thermal decomposition were studied. The requirement for improved fire safety and combustion knowledge to support the testing, validation, and design of future missions in a variety of environments is what motivates this research. To optimize propulsive designs for effective performance and minimization of current shortcomings. The results are likely to help in devising accurate energy prediction systems by developing suitable correlations on the basis of experimental outcomes for efficient energy transfer prediction and thus better and safer missions.


**Keywords:** external energy source, fire spread, energy transfer, configurations, surface orientation, heat source and sink effect

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## Introduction

Combustion is the primary source of energy generation and is required for fulfilling the world's 80% energy requirement. Combustion is essentially classified as normal combustion and smoldering. Normal combustion (flaming combustion) is observed when burning is accompanied by flame. However, Smoldering (flameless combustion) takes place in the absence of flame. The research investigates the behavior of diffusion flame under the realm of flaming combustion. There are two types of fires classified based on their propagation namely propagating fire and stationary fire. Propagating fires involve the propagation of flame normal to the surface. Stationary fires do not propagate from the ignition front. The fire phenomenon is principally researched as (a) Opposed flow fire and (b) Concurrent flow fire. In concurrent flow fires, improved heat transfer to unburned fuel facilitates fire's spread in direction of flow. Conversely, in opposed flow fires, opposite flow direction prevents the fire from spreading. Because of this, there is less heat transfer to unburned fuel, & the flame spread is steady, slow, and easier for analysis. The study focuses on the behavior of diffusion flame in opposed flow spreading fire. This is done as the downward spreading flame is slow, steady, and easy to analyze unlike concurrent (upward spreading flames).60% of fire accidents occur due to uneven energy transfer (refer Figure 1). There was a significant increase in structured fire loss up by 10.7 billion (USD), 8.5 million acres of forest land burned, consistency in Aircrafts and Rocket Crashes, system testing and validation accidents, and irreplaceable loss of mankind (Thousands) with annual Rise by 77% (*NFPA).

It is imperative to look for ways to avoid disasters that cause huge damage to Nature, life and property. However, there is no closed form solution to avoid such accidents. Fires can be detected, prevented and possibly suppressed. The uneven energy transfer associated with propagating fires makes it unable to find a solution. Following Kim and DeRis's.,[1] classical work on laminar burning between parallel fuel surfaces. The 2D, vertically downward propagation of flame having numerous parallel paper sheets in air was subject of Itoh and Kurosaki's.,[2] work. The separation distance has been applied to divide the flame spread regime. This has been revealed that flame spread rate in wider space regions exceeded that of single paper sheet and peaked at finite separation distance. Additionally, it expanded as sheet's number rose as well as asymptotically approached constant value. However, because there can be no flame in the small gap between sheets of paper, flame had been seen to be impossible to extend vertically downward over 3 parallel sheets of paper within narrow space zone. In both normal gravity as well as microgravity, Urban[3] investigated interactions among flames growing over parallel solid paper sheets.

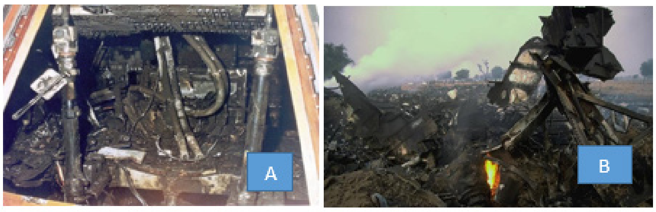


**Figure 1** (A) Pictorial representation (A) Apollo 1 (1967) (*google.com*), (B) Kazakhstan Airlines (*google.com*).

To reveal the impact of parallel sheets on oxidizer transport & radiative feedback, tests were executed at various pressures as well as separation distances. The findings revealed that because of the radiant & diffusive interactions among surface & flames above it, spatial distribution could substantially affect the pace of burning and/or spread. The impact of humidity along with temperature on downward flame spread over combustible substances was investigated through experimentation by Suzuki et al.,[4] The tests for flame spread were conducted in a vertical duct that had been attached to a wind tunnel nozzle. A humidifier & heater were placed in wind tunnel to regulate humidity & temperature of the air flowing through duct. The humidity was greatly altered, and the temperature & velocity had been set to 20°C or 30°C & 10cm/s, correspondingly. This has been revealed that rate of spread of flame in both the gas as well as condensed phases is assumed to be affected by humidity. Additionally, weight of water absorbed by paper relative to paper sheet is closely associated with relative humidity rather than absolute humidity and is independent of paper thickness. A largely reusable space transportation system was investigated by Sippel et al.,[5] as part of German future launcher technology research program ASTRA. This has been made of dual booster stages that were involved to Ariane 5 core. Current developments in design of reusable booster stage have been detailed in the preliminary design study. The work evaluated long-term, strategic scenarios for functioning of reusable stage. Reusable First Stage for small launcher, potentially fully reusable system, and booster for super-heavy-lift rocket to support ambitious space flight programs like manned Mars missions used fly-back booster vehicles for 3 space transportation systems. Technical sanity, preliminary sizing, as well as performance difficulties, were all covered in detail in the assessment, which also looked at other solutions as necessary. DeRis and Orloff.,[6] examined the heat-flux distributions & flame heights of a variety of fuels burning among two parallel panels. The sootiness of the fuel has substantial impact on flame heat flux levels. Regardless of fuel type or fire size, measured flame heights suggested a real heat release rate per unit flame volume.

To find net total heat transfer to the panels above a randomly chosen panel, the heat flux distributions had been integrated. A basic theoretical model that assumed heat transmission solely happened by radiation was utilized to explain the outcomes. The model gave the net heat transfer as function of flame volumetric heat release rate, parallel panel width, separation, fuel smoke yield, gas equivalent smoke yield, along with fire heat release rate. Rein[7] brought together contributions from various scientific areas to give a complete view of smoldering combustion. The development of innovative power and environmental technologies on the basis of direct utilization of smoldering combustion was underlined in the discussion. The study stated that although there were clear signs of new scientific and engineering prospects in smoldering combustion, more multidisciplinary experimental, theoretical, and field studies were needed, necessitating a considerably larger worldwide research effort. Liu et al.,[8] examined burn-out time data from experimental square fire arrays to study spatial burning rate dispersion in group fires with multiple fire locations. The "fire layer," a novel concept, was created for describing spatial locations of fire points. This made it possible to physically evaluate and analyze complex spatial variations in burning rates under various circumstances. Analysis revealed that fire layer burning rates exhibit distinct nonlinear modes that differ from outer to inner. The results showed that there are different spatial fluctuations in fire arrays for the 2 fire interaction impacts, air supply restriction & heat feedback expands. Both primary parameters, fire array size & fire spacing, were found to have a large impact on spatial fluctuations of 2 interaction affects. Average burning rates of every fire layer fluctuate consistently with fire spacing or fire array size, especially with considerable comparison to whole fire array. Fire layer burning rates varied with fire array size, while average burning rates for all fire layers fluctuated linearly v/s fire area ratio within same ranges as full fire array when fire spacing was adjusted. A revolutionary method for calculating fire propagation among fuel sources shows that close new fire sites increase burning rates of older ones. A 2-D numerical research of opposing flow across a range of thin solid fuel sheets in microgravity setting was conducted by Malhotra et al.,[9] The outcomes highlighted that because of greater heat feedback to solid fuel and decreased radiation losses from flame, flame spread rates for multiple-fuel configuration are larger compared to those for flame spreading over single fuel sheet. As interspace distance among fuel sheets declined, flame spread rate exhibited non-monotonic fluctuation.

Rise in same spread rate with decreasing interspace distance was determined to be caused by greater radiation heat feedback, mostly as gas or fame radiation. Both single as well as multiple fuel sheet arrangements showed a drop in the extinction oxygen limit with a fuel emittance of zero. Although research on flame interactions has been prolific, it has mostly focused on candles and droplets because of their practical relevance. The booster and a roughly $200 million Israeli communications satellite were destroyed when SpaceX Falcon 9 rocket[10] burst in last minutes of staged countdown at Cape Canaveral. Both rocket & Amos 6 satellite were destroyed in the crash. The anomaly started near (the) upper stage oxygen tank and happened while RP-1 kerosene as well as liquid oxygen propellants had been pumped aboard launcher. Initial design of the Challenger SRB (Solid Rocket Boosters) Field Joint had been considered direct reason for shuttles' catastrophic failure during liftoff, as Jenab and Moslehpour.,[11] reiterated. It was claimed that the Field Joint SRB was essential to keeping the hazardous gases generated in the SRB contained. Following the Challenger accident investigation, FTA (Fault Tree Analysis) had been created to examine SRB field joint configuration's dependability with respect to its objectives. Field joint's operational reliability was lacking, as demonstrated by the reliability model. To obtain a physical understanding of acoustic thermal energy interaction & its consequences for smoldering combustion, Tiwari et al.,[12] conducted an investigation. Incense stick experiments were conducted utilizing a fixed frequency, varying surface orientation, and appropriately varying the distance among fuel & sound sources.

Variations in fuel regression rates were employed to evaluate the impact of acoustics under various circumstances. The outcome demonstrated that thermoacoustic interactions improve the forward heat transfer rate as source separation distance varies. Recently, Park,[13] analyzed building fire, forest fire, and warehouse compartment fire are some of the most frequently occurring practical fire hazards in modern world. An unstable 2-D numerical model had been utilized for simulating simultaneous flame spread over paper alike thin solid fuels in discrete configurations in both normal gravity (1g) as well as microgravity (0g). Ten fuel segments, each 1cm long, were evenly spaced either vertically (1g) or in the flow direction (0g). Both the fuel burning rate & the same base spread rate had been examined. It was observed that the spread rate in 1g and 0g expanded as the separation distance rose. When upstream segment burns out, flame base is compelled to jump to next fuel segment due to gaps in discrete fuel. It was observed that the fuel burning rate behaved differently among 1g and 0g. The explanation given was that a reduced burning rate results from a decline in the preheating length, or fuel area exposed to flame, as the separation distance grows. The phenomenon was consistent over the whole set of fuel segments in all simulated configurations, extending to final fuel segment prior to first fuel segment burnt out. Nevertheless, in certain configurations, the flame fractured into several flamelets, and flame standoff distance declined in spaces between fuel segments. A noteworthy arrangement for tackling the difficulties at hand has been formed as a consequence of the substantial scientific contributions. However, a full and comprehensive understanding of the problems has been impeded by the existence of heterogeneous heat and mass transmission. The present research focuses on problem comprehension and the introduction of practical physical awareness to improve the critical comprehension of whole process to accomplish efficient combustion & propulsion. The goal of the project is to boost fire safety and get closer to safer space trips in the future by making rockets as well as other spacecraft more fire-resistant. The following essential objectives accompany the "work:

a) To explore fundamentally the effect of external energy source(s) on pilot fuel burning and draw suitable implications in terms of applications.

b) To predict the energy transfer in pilot fuel ignition and external heat source(s) for linear and non-linear design configurations.

c) To understand the role of key controlling parameters and establish appropriate co-relations between them.

## Experimental setup and solution methodology

For" selected applications simple trial setup had been created as well as utilized. Fuel strips had been marked at 3 regular intervals of 1cm. Apex of fuel strip was introduced to pilot flame. Readings were taken after uniform horizontal ignition. Five minutes were allotted for experimental simulations to restore the room atmosphere to normal. The split times were measured utilizing a stopwatch (refer to Figure 2).

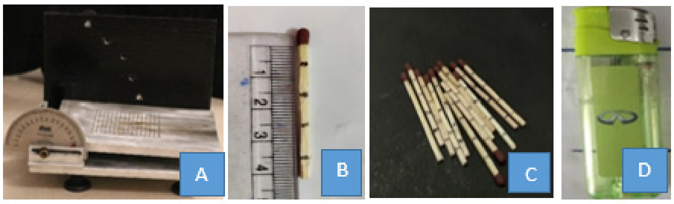


**Figure 2** (A) Pictorial representation of the experimentation setup, (B & C) Matchstick as Fuel and external energy source(s), (D) gas lighter as ignition source.

Flame spread rate ($r$) has been computed as:

$$\gamma = \frac{\int q_{net}}{\rho_s \tau_s c_s (T_{surface} - T_\infty)} \quad (1)$$

Flame spread rate is rate at which surface burns, and it has been determined linearly as:

$$\gamma = \frac{Distance\ burnt}{Time\ taken\ to\ burn\ that\ region} \quad (2)$$

***Forward heat transfer theory***

From the 2nd form of Energy Equation

Net Energy=Energy Generated–Energy Lost.

$$q_p - q_L = \rho_s C_s V(dT/dt) \quad (3)$$

$$where,\ q_p = \Delta H_c V C_t A * e^{(E_a/RT)} \quad (4)$$

$$q_L = hA(T - T_a) \quad (5)$$

It is crucial to remember that all of the data displayed has an error margin of ±2% and indicates repeatability & reproducibility of order 3.

## Results and discussion

Initial single fuel spread rate tests with surface orientation variation. Figure 4 demonstrates various distribution of surface orientation rates. Non-monotonic trend maximum 83.10mm/min at 45° and minimum 60mm/min at 0°. It "ensures experimental setup predictions reasonably with traditional Heat Transfer Theory and previous studies.[1,2] Predictions of experimental setup probably provide good physics understanding of propagation phenomenon. Single fuel values were used as reference for comparison (refer to Figure 4). Heat feedback, or forward heat transfer, widens propagation front from burning to unburned solid fuel upstream" in thin solid fuels, according to standard heat transfer theory. Consequently, spread rates may grow or fall (refer to equation 1). Convective buoyant flow causes temperature fields, localized velocity, as well as convective buoyant movement to form throughout "fuel surface. High-temperature smoke preheats and provides energy parallel to fuel surface. High cumulative heat transfer from burned to unburned areas might cause high spread rates. Remaining outcomes had been grouped into three categories viz., zones for different approaches and dynamic systems (refer to table 1) (refer Figure 3).

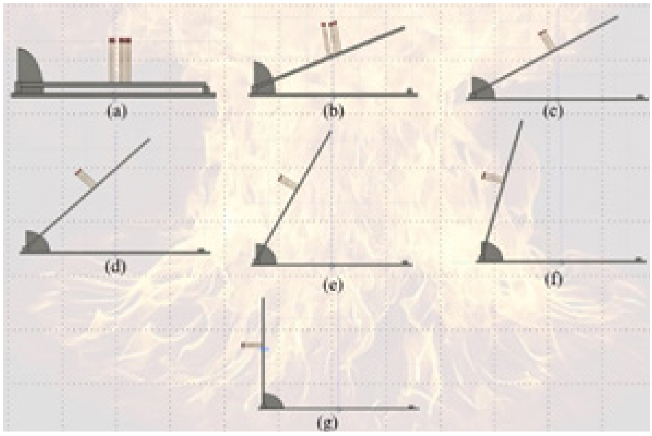


**Figure 3** (a) Pictorial representation of the experimentation setup, Matchsticks kept at different orientations: (a) 0°(b) 15° (c) 30° (d) 45° (e) 60° (f) 75° (g) 90°.

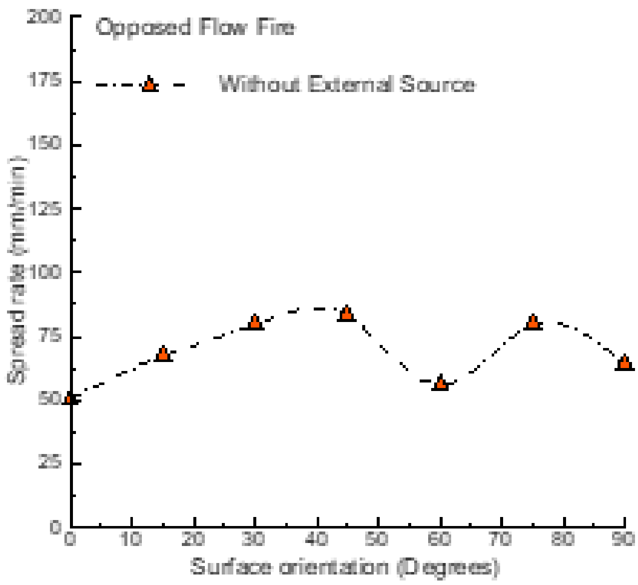


**Figure 4** Variation of spread rate with surface orientation.

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**Table1** Variation of 'Spread rate coefficient 'Ψ' with surface orientation for different models. (a) Uni-lateral configuration, (b) Bi-lateral configuration, (c) Tri-lateral configuration, (d) Quad-lateral" configuration, (e) Mat-lateral configuration

**(a)** Uni-lateral configuration

| Surface orientation (Degrees) | LTI | NLTI | LTV | NLTV |
|---|---|---|---|---|
| 0 | 1.18 | 0.936 | 0.672 | 0.769 |
| 15 | 0.989 | 0.9 | 0.731 | 0.845 |
| 30 | 0.665 | 0.468 | 0.63 | 0.583 |
| 45 | 1.083 | 0.575 | 0.406 | 0.511 |
| 60 | 1.281 | 1.335 | 1.569 | 1.102 |
| 75 | 0.81 | 1.058 | 1.572 | 0.778 |
| 90 | 2.007 | 1.643 | 1.568 | 1.999 |

**(b)** Bi-lateral configuration

| Surface orientation (Degrees) | LTI | NLTI | LTV | NLTV |
|---|---|---|---|---|
| 0 | 0.827 | 0.679 | 1.063 | 0.7 |
| 15 | 0.742 | 0.515 | 0.676 | 0.824 |
| 30 | 0.58 | 0.582 | 0.637 | 0.701 |
| 45 | 0.802 | 0.616 | 0.548 | 0.637 |
| 60 | 1.068 | 1.252 | 1.641 | 1.172 |
| 75 | 2.268 | 1.467 | 1.113 | 1.172 |
| 90 | 1.561 | 1.597 | 1.536 | 2.83 |

**(c)** Tri-lateral configuration

| Surface orientation (Degrees) | LTI | NLTI | LTV | NLTV |
|---|---|---|---|---|
| 0 | 1.368 | 1.009 | 1.223 | 0.676 |
| 15 | 0.672 | 0.821 | 0.535 | 0.577 |
| 30 | 0.565 | 0.696 | 0.809 | 0.662 |
| 45 | 0.746 | 0.663 | 0.96 | 0.711 |
| 60 | 1.686 | 1.083 | 1.04 | 0.793 |
| 75 | 1.334 | 0.898 | 1.397 | 0.828 |
| 90 | 1.561 | 2.534 | 1.165 | 0.398 |

**(d)** Quad-lateral" configuration

| Surface orientation (Degrees) | LTI | NLTI | LTV | NLTV |
|---|---|---|---|---|
| 0 | 1.186 | 1.003 | 1.287 | 1.056 |
| 15 | 1.028 | 0.694 | 0.783 | 0.726 |
| 30 | 0.58 | 0.614 | 0.923 | 0.668 |
| 45 | 0.773 | 0.594 | 0.816 | 0.715 |
| 60 | 1.186 | 1.231 | 1.205 | 1.374 |
| 75 | 1.03 | 1.109 | 0.909 | 1.571 |
| 90 | 1.041 | 1.669 | 1.172 | 2.031 |

**(e)** Mat-lateral configuration

| Surface orientation (Degrees) | LTI | NLTI | LTV |
|---|---|---|---|
| 0 | 1.898 | 1.156 | 1.196 |
| 15 | 0.774 | 0.644 | 0.595 |
| 30 | 0.453 | 0.746 | 0.704 |
| 45 | 0.63 | 0.6006 | 0.379 |
| 60 | 1.095 | 1.161 | 0.947 |
| 75 | 1.023 | 1.376 | 1.627 |
| 90 | 1.455 | 1.504 | 2.197 |

a) **Heat sink zone:** Heat transfer in this regime is diminished because of decline in concentrated temperature surrounding pilot fuel. Explanation for this is that there isn't enough oxygen to fume pilot fuel. As a result, when applied to the pilot oxygen, the spread rate for such case is lower.

b) **Neutralizing zone:** Heat transfer in this zone is identical to that of pilot fuel. In this case, spread rate is similar in pilot fuel base example.

c) **Heat source zone:** This zone is characterized through cumulative heat transfer because of buoyancy, which moves heat from burned to unburned fuel. As consequence, spread rate for this situation is more in comparison to pilot oxygen burning fuel.

To better understand the data, new non-dimensional number, spread rate coefficient (Ψ) has" been formulated and its variation has been studied for understanding related energy transfer.

$$ø = \frac{\textit{Spread rate in presence of external thermal energy sources}}{\textit{Flame spread rate of pilot fuel without any external sources}}$$

**Spread rate coefficient (Ψ)** indicates "nature of Secondary System and details energy transfer.

'Ψ'>1 implies Heat Source Effect

'Ψ'=1 implies Neutralizing Effect

'Ψ'<1 implies Heat Sink Effect

According to Spread Rate Coefficient Ψ, Table 1(a-e) focuses detected coupled heat source and heat sink effect (Table 1).

"**VRMAMIK conjecture**" denotes counter-behavior through similar articulate under comparable circumstances in relation to time, is a new noteworthy distinction as per explanations with significant differences and distinct counter-behavior from heat source(s) in form of potential heat sink(s). Conjecture is vital to comprehend the heterogenous fire behaviour. In most situations, behaviour is constituted of 'Upsurging-steady fluctuations- downgrade' flames. This could be explained by the system's energy transmission being significantly impacted by shift of localized flame zones into combined big "flame. Figure" 5 reveals how surface orientation affects unilateral LTV model spread rate. In the current scenario, three external energy sources at 5, 10, 15mm from virgin fuel are linearly fixed. Deportation time (10seconds) eliminates nearest external energy source to pilot fuel. Later, inadequate external energy supply affects pilot fuel spread rate. Uneven energy transmission in non-monotonic patterns has been extensively studied. Maximum spread rate of 124.826 mm/min has been found at 75° orientation. At 45°, minimum spread rate was 33.771mm/min. Maximum decline of **59.361%** was reported at 45° surface orientation, whereas maximum increase was **57.290%** "at 75°.

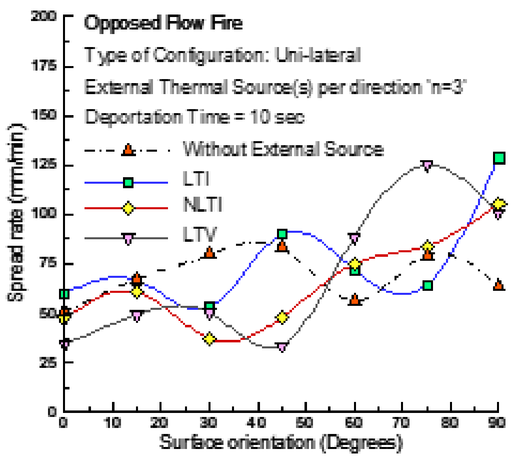


**Figure 5** Variation of Spread rate with Surface orientation on Linear Time variant (LTV) Dynamic Fire Spread System on Pilot fuel spreading rate in unilateral configuration.

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External energy sources are heat sinks from 0°- 45°. However, VRMAMIK Conjecture shows that identical external energy sources are heat sources. The spread rate coefficient Ψ ranges from 0.4 - 1.57, indicating a shift from heat sink to heat source effects (refer Figure 6). Figure 7 demonstrates how surface orientation affects bilateral LTV model spread rate. Six external energy sources—three on each side of pilot fuel—are fixed. 3 external energy sources at 5, 10, 15mm" from virgin fuel have been linearly fixed on both sides. Presence of nearest energy sources has been hindered to 10s. As a result, they were eliminated in 10 seconds. The "distribution rate of pilot fuel is influenced through restricted availability of the nearby energy sources as has been found. A non-monotonic pattern indicating unequal energy transfer has been thoroughly investigated. This verifies heterogeneous energy transfer included in propagation of fire. Spread rates examined from orientations of 0°- 45° indicated" values in similar range of 45.5-53.8mm/min. Yet, rise in spread rate of 92.213 mm/min has been detected at 60° orientation. At 90 degrees, spread rate has been highest at 98.414 mm/min, while at 15 degrees, it has been lowest at 45.53 mm/min. The notable escalation in "spread rate at 60° displays largest percentage rise of **64.141%.**

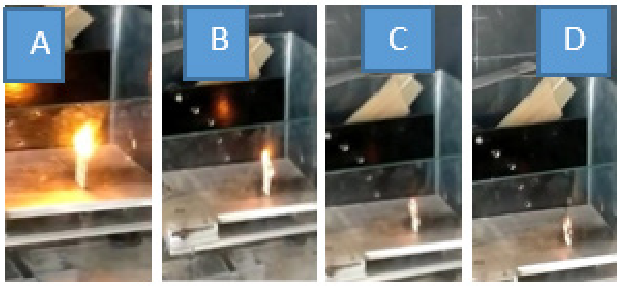


**Figure 6** Pictorial representation of the Uni-Lateral Configuration experimentation: (a) 10sec (b) 20sec (c) 30sec (d) 40 sec.

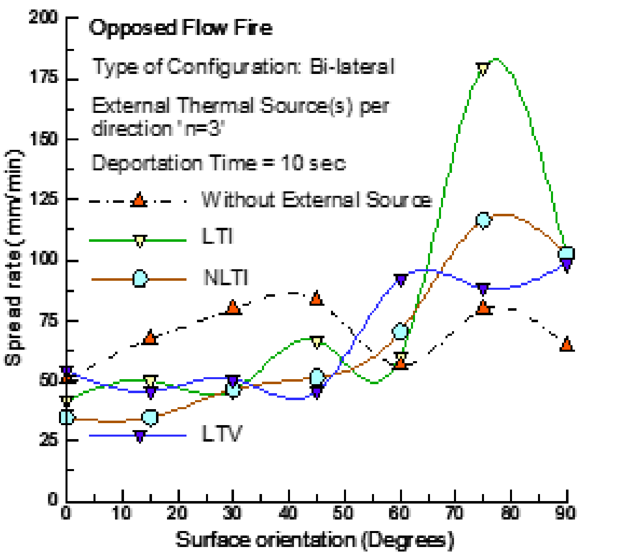


**Figure 7** Variation of Spread rate with Surface orientation on Linear Time variant (LTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Bi-lateral configuration.

Greatest percentage decline of **45.178%** has been reported at 45°. Neutralizing" impact has been detected at 0°. Although, heat sink impact ranges from 0°- 45°. The external energy sources were found to exhibit a counter-behavior. From 60°-90°, they behave like heat sources. Thus, the spread coefficient is 0.5-1.3. Experimental simulations in bilateral LTV model configurations show an intentional change from neutralizing to heat sink and ultimately heat source "effects.

Figure 8 depicts influence surface orientation has on spread rate in Trilateral configuration" of LTV model. 3 "external energy sources are fixed in linear configuration 5, 10, 15 mm from Pilot fuel in 3 120° slanted directions. The three closest external energy sources to virgin fuel—each 120° apart—were deported in 10 seconds. The availability of three nearest external energy sources is changed over time. The spread rate curve follows a hybrid trend. The lowest drop-in spread rate is 36.036 mm/min for 15° orientation. The highest measurement was 110.95 mm/min for 75° orientation. The largest rise was 39.749% for 75° orientation while the maximum drop was 46.486% for 15° orientation. Range of a heat sink effect is 15°- 45°having spread rate coefficient values between 0.5 and 0.9. External energy sources exhibit a neutralizing impact at 60° orientation, with a spread rate coefficient of 1. Still, heat source effect has been detected at 75° and 90° orientation.

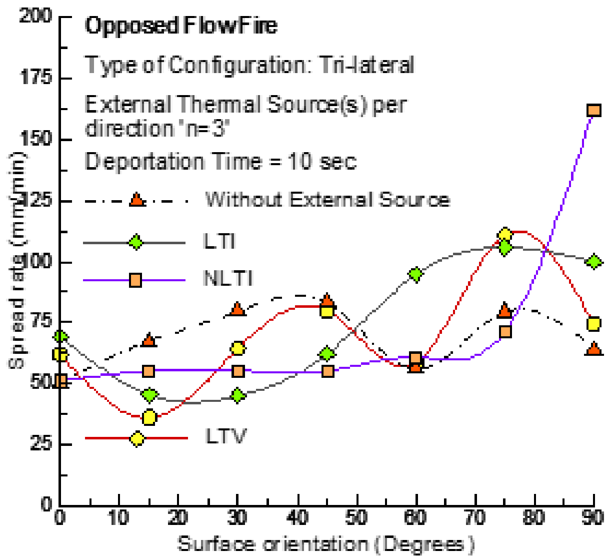


**Figure 8** Variation of Spread rate with Surface orientation on Linear Time variant (LTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Tri-lateral configuration.

Figure 9 demonstrates how surface orientation affects LTV quad lateral spread rate. Current example has 12 external energy sources around pilot fuel. 3 external energy sources are linearly spaced 5, 10, 15mm from pilot fuel and" opposing other 3 energy sources. 6 diametrically opposite external energy sources are linearly fixed. With the exception of the orientation of 15°, the spread rates at all orientations fell between 65-75 mm/min. 15° orientation led to lowest decrease of 52.77 mm/min. Subsequently, "highest percentage drop-in spread rate of **21.636%** has been recorded at 15° orientation yielding maximum value of" 75.093 mm/min. Largest percentage growth of **28.727%** has been evaluated at 15° orientation. Restricted availability of external energy sources resulted in noticing heat sink behavior of external energy sources at orientations of 15°, 30°, 45°, 75°. Nevertheless, heat source effect has been carefully investigated at 0°, 60°, 90°. This is vital to maintain that every plot shows the spread rate variation of pilot fuel recorded under various circumstances of particular surface "orientations, approaches, configurations.


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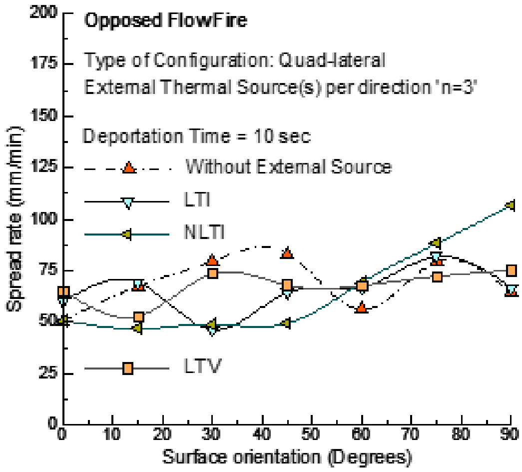


**Figure 9** Variation of Spread rate with Surface orientation on Linear Time variant (LTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Quad-lateral configuration.

Figure 10 illustrates effect surface orientation has on spread rate of virgin fuel in Matrix lateral configuration of LTV model. A 3×3 matrix configuration was adopted to analyze the coupled heat source and heat sink effect that external energy sources have on the spread rate of pilot fuel. Every external energy source was fixed at interspatial distance of 5mm" from each other. A non-monotonic hybrid trend was carefully observed from orientations of 0° to 60°. However, from 75°, we analyze monotonic increase in spread rate. Maximum spread rate of 140.734 mm/min has been obtained at 90° orientation and minimum spread rate of 31.578 mm/min has been noted at 45° orientation. Consequently, maximum spread rate gave the maximum percentage rise of **119.780%** at 90° orientation and the minimum spread rate produced a maximum percentage drop of **62%** at 45°. Moreover, a heat sink effect phenomenon stretches from orientations 15° to 60°. From 75°, we see heat source effect. This proves presence of VRMAMIK "Conjecture. Figure 11 demonstrates how uneven energy transfer in NLTV Dynamic Fire Spread System affects pilot fuel spreading rate. Case involved unilateral setup. Three non-linear external energy sources at 5, 10, and 20mm from virgin fuel have been fixed. The" closest external energy source to pilot fuel has 10s. Without external energy sources, spread behavior was restricted. Spread rate was non-monotonic between 0° and 45°.

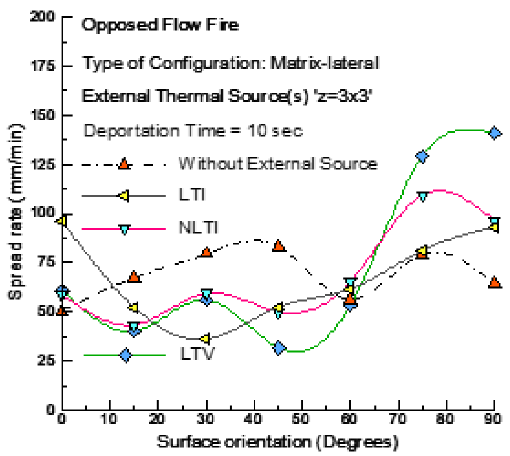


**Figure 10** Variation of Spread rate with Surface orientation on Linear Time variant (LTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Matrix-lateral configuration.

Though, monotonic elevation in spread rate later followed from 45° orientation. Spread rate values elevated because of limiting availability of the closest external energy source. This highlighted a distinct heat source impact. The maximum increase of 128.022 mm/min recorded at 90 degrees. As a result, this orientation contributes to highest rate of change of **99.92%**. Lowest spread rate of 38.918 mm/min has been reported at 0°. Lowest percentage drop-in spread rate of **48.86%** has been recorded at 45°. Figure 12 depicts impact of related uneven energy transfer in NLTV Dynamic Fire Spread System on Pilot fuel spreading rate. During present situation, Bilateral arrangement has been chosen to conduct our spread rate analysis. Three external energy sources were fixed in non-linearity at interspatial distances of 5, 10, 20mm from virgin fuel, respectively, while another set of energy sources was positioned diametrically opposite similarly. Nearest external energy sources from both sides are only 10s old. It" caused non-monotonic spread rate up to 45°. Flame spread rate rises monotonically from 45°. The highest spread rate is 181.268mm/min at 90° and the lowest is 35.419mm/min at 0°. Spread rate changed at a non-monotonic rate. The largest percentage rise has been **183.080%** reported at 90° while lowest percentage drop of **35.419%** was at 0°. Heat sink effect has been assessed from 0°-45°. Heat source effect has been noticed at 45°.

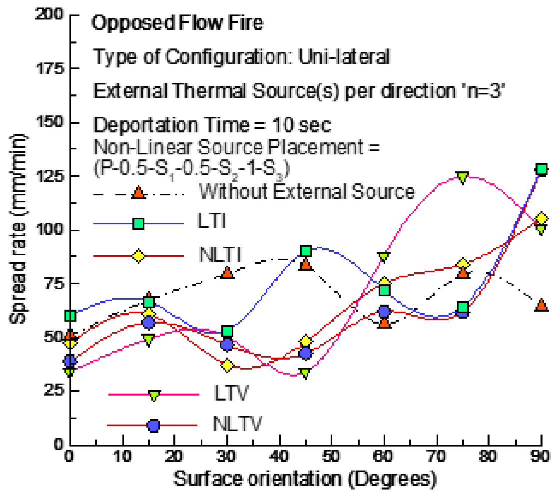


**Figure 11** Variation of Spread rate with Surface orientation on Non-Linear Time variant (NLTV) Dynamic Fire Spread System on Pilot fuel spreading rate in unilateral configuration.

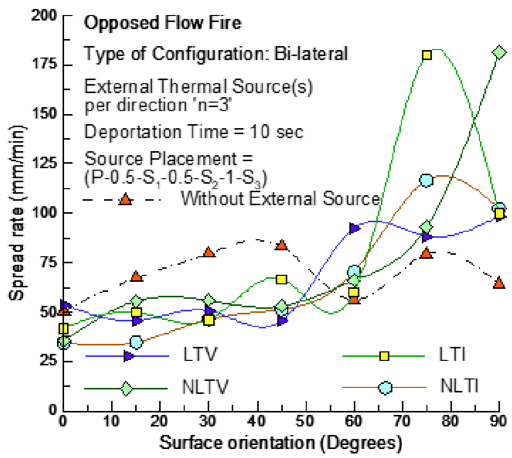


**Figure 12** Variation "of Spread rate with Surface orientation on Non-Linear Time variant (NLTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Bi-lateral configuration.

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Impact of associated uneven energy transfer in NLTV Dynamic Fire Spread System on pilot fuel spread rate in trilateral configuration is depicted in Figure 13. In this scenario, external energy sources were linearly fixed 5, 10, and 20mm from Pilot fuel in three 120°-inclined directions. Non-linear interspace distance and nearest external energy sources were used. Thus, pilot fuel distribution in non-monotonic hybrid pattern was affected by nearest 3 external energy sources to virgin fuel, removed in 10s. Maximum" spread rate at 75° is 65.765 mm/min. Distinctiveness of the trilateral structure in NLTV model has been seen at 90° orientation. We find an anomaly that goes against scientific predictions about spread rate behavior at 90° orientation. Former generates lowest spread rate of 25.523 mm/min. Furthermore, experimental simulations performed in this situation capture heat sink effect only. Largest percentage drop is **60.141%** at 90°. Figure 14 demonstrates how unequal energy transfer in NLTV Dynamic Fire Spread System affects quadrilateral pilot fuel spread rate. The pilot fuel is surrounded by 12 external energy sources. 3 non-linear external energy sources are located 5, 10, 20mm from pilot fuel and opposing other 3 energy sources. 6 external energy sources are nonlinearly fixed at other diametric ends. Overall, the" spread rate increases monotonically from 15° to 90°; the maximum spread rate at 90° was 130.057 mm/min, while the minimum spread rate at 15° was 48.908 mm/min. The largest percentage increase in **103.106%** has likewise been seen at 90°. But, biggest percentage decline of **33.131%** has been acutely detected at 30°. Linked heat source and heat sink impact have been examined using flame behaviour. Spread rate coefficient Ψ values verify analysis. At 0°, flame displayed neutralizing effect. Later, seamless shift from heat sink zone has been seen from 15° to 45° leading to heat source effect from 60° to 90°.

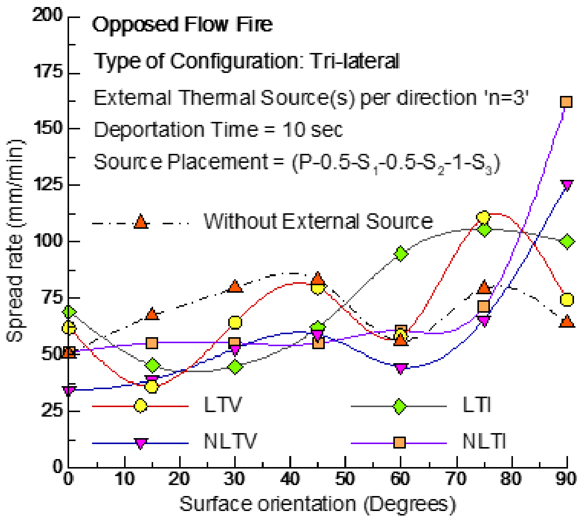


**Figure 13** Variation "of Spread rate with Surface orientation on Linear Time variant (NLTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Tri-lateral configuration.

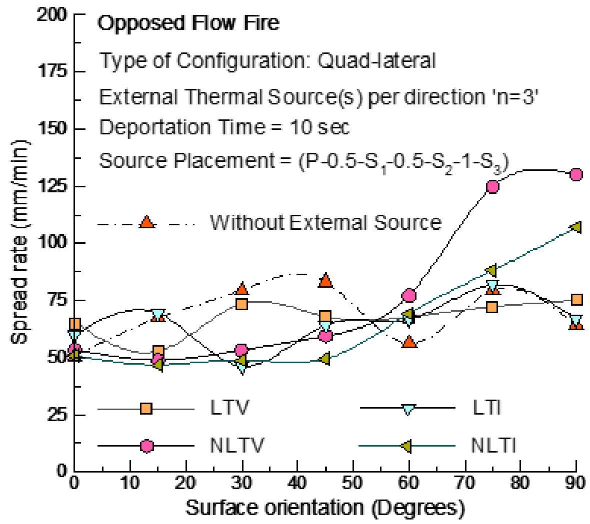


**Figure 14** Variation "of Spread rate with Surface orientation on Linear Time variant (NLTV) Dynamic Fire Spread System on Pilot fuel spreading rate in Quad-lateral configuration.

## Conclusions

In the study carried out, 4 unique models, NLTV, "Linear Time-Invariant (LTI)", LTV, & "Non-Linear Time Invariant (NLTI)" were designed to recreate real fire spread circumstances occurring in rocket and plane crashes. To accurately evaluate the spread rate of pilot fuel in availability of linked heat source and heat sink influence, each model included a variety of configurations, including unilateral, bilateral, trilateral, and quadlateral. The effect of external energy source(s) in the form of heat & and heat sink effect was evaluated. To characterize the secondary system, novel non-dimensional number called the **Spread Rate Coefficient (Ψ)** has been developed. The "VRMAMIK Conjecture" is a novel theory that was discovered. This is reflection of counter-behavior through similar articulate under similar situations with respect to time. The **VRMAMIK Conjecture**, which defines heterogeneous nature of fires independently with surface orientation, was validated by spread rate coefficient (Ψ), spread rate variation, and values. From research carried out, subsequent conclusions might be drawn:

**a)** The transmission of fire does not have a definite pattern. Measurements of the spread rate of pilot fuel were used to conduct experiments that allowed for a thorough and comprehensive observation of its diverse behavior. The pilot fuel had been exposed to a variety of fuels in five configurations that were used in four models that took time and space variation into account.

**b)** Critical analysis was done on "rapid self-ignition, a decrease in flame intensity over time, flame merging and segregation, the creation of limited flame zones, instability with unsteadiness, the reemergence of steady fire.

**c)** Variable surface orientation greatly impacted fire behavior leading to situations of partial, total burning and extinction.

**d)** An unexpected high heat source effect of 180 mm/min at 75° orientation is displayed by Linear Time Invariant model in Bilateral arrangement.

**e)** **Applications of the present work:** Present work can be effectively utilized for detection, suppression and possibly

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prevention of rocket and plane fires. Hence, it will be very useful in the prevention of rocket and mid-air plane crashes. Many financial and human losses shall also be avoided. Additionally, device with help of data gathered from experimental simulations could be developed. The device" could reduce the number of rocket and plane crashes that have been occurring as a result of the fire's heterogenous spread.

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None.

## Conflict of Interest

The authors declare that there is no conflict of interest.

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