Probabilistic approach for biorhythmic analysis to prevent aviation accidents

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Abstract: This paper presents a new methodology, based on the probabilistic approach, for biorhythmic analysis to prevent aviation accidents. The methodology has been developed using the Gaussian distribution technique for reliability evaluation of the aviation system, keeping in mind the biorhythmic effects of the pilot. The normal distributed data of the US Air Force were tested and analysed based on the performance ability of pilot and the peak demand of the performance. The accident zone is that area of operation during which the performance demand exceeds the performance ability of the aircraft pilot. Failure probabilities, considering peak performance demand and the pilot’s ability, have been evaluated using the Gaussian distribution approach. The safety factor concept has also been presented in this paper for biorhythmic analysis to prevent aviation accidents. The stepped incident-duration curve has been utilised to evaluate the pilot’s reliability on the aviation system using Simpson’s 1/3rd rule.

Keywords: aviation accidents; biorhythmic approach; incident-duration curve; performance ability of pilot; performance demand; accident prone zone/critical day; Gaussian distribution; reliability evaluation; safety factor.
1 Introduction

The word BIORHYTHM is derived from the Greek words BIOS, which means life and RHYTHM, which means flowing with regular moment of life events. Biorhythm theory mostly uses scientific methods to chart the rhythms (cycles) that affect the internal functioning of the body and human behaviour, particularly the physical, emotional and intellectual (mental) abilities. The biorhythm theory states that, at the moment of birth three statistical cycles are initiated and recur consistently throughout a person’s life. Our productivity, efficiency, intelligence and activity levels are not just matters of will power. Thommen (1973) has explained that every one of us is subjected to certain biological rhythms. The three biorhythm cycles have independent durations and influences. These cycles comprise the classical theory, which became popular with the
The earliest observed biological cycles were recorded by Alexander the Great’s scribe, Androsthenes, in the fourth century BC. Many studies done abroad and in the USA of America during the 1940s and 1950s demonstrated a higher disposition towards accidents and human error that coincided with these biorhythmic cycles. The physical, emotional and intellectual biorhythm cycles have sinusoidal characteristics as shown in Figure 1 and have 23, 28 and 33 days duration, respectively. At birth all these cycles begin at zero and follow the above sinusoidal characteristics, first going in the plus direction (upwards), returning to zero (mid cycle), then going in the minus (downward) direction, turning around and returning to the positive to begin the cycle again. Biorhythm cycles are composed of positive phase, negative phase and nodal points where the curve crosses the abscissa. According to Hines (1998) each cycle starts on the first positive phase at the moment of birth, the positive phases correspond to periods of better performance, and the negative phases correspond to periods of poor performance and greatest susceptibility. Critical periods are usually of 24 h/48 h duration. The physical cycle has a 23 days period and affects a broad range of physical factors, like resistance to disease, strength coordination, speed, other basic body functions and the sensation of physical well-being. The emotional cycle has a period of 28 days and affect creativity, sensitivity, mental health and mood etc. The intellectual cycle has a period of 33 days and it affects memory, alertness, and the receptivity of knowledge and logical analytical functions of mind. Since the periods of all three cycles are different (23, 28 and 34 days), the interaction of the three cycles overlaid on top of each other is rather complex. They do not appear in this exact configuration again for 21, 252 days or 58 years and 66–68 days, depending on leap years. The theory of Davis and Roger (2006) predicts that accidents will occur more on accidents prone days; on these days more than one cycle out of the three crosses the abscissa. Zimmerman (2001) has presented an example study related to biorhythm, popular in the late 1970s, used to illustrate the separating of scientific evidence and pseudo-science hype. The cited biorhythm study focuses on the relationship of the accident dates and the three biorhythm cycles. John et al. (2006) have managed human factors in non-destructive evaluation which are critical to maintain inspection reliability. Reliability of structural health monitoring systems is particularly sensitive to sensor degradation over time. To investigate the impact of these issues, probabilistic models for risk assessment and cost benefits analysis have been developed. Quantitative studies are presented evaluating the effects of variations in the probability of detection associated with human factors, plus in situ sensor degradation of life cycle measures such as cost and probability of failure.

This paper is organised as follows, keeping in mind pilot error factors in aircraft accidents, a human factor approach to aircraft accident analysis, the human factor in cycle accident patterns, statistical analysis of the accident data and reliability evaluation of the system based on different probabilistic approaches. Section 1 describes the meaning of the word ‘Biorhythm’ and presents a brief history. Section 2 presents an overview of typical natural biorhythm cycles, namely, physical, emotional and intellectual cycles, in detail. Causes of air craft accidents, including direct and indirect causes, have been highlighted in Section 3. Statistical techniques for biorhythmic analysis on accident prone days have been described in Section 4. Section 5 discusses the reliability analysis of the biorhythmic aviation accidents. The Gaussian distribution approach, failure probability evaluation approach, safety factor concept and peak load considerations approach and performance evaluation approach using Simpson’s 1/3rd have been presented in Section 5. Section 6 represents various results and discussions
based on biorhythmic data. The conclusion and future research work plans in the area have been presented in Section 7.

2 Typical biorhythm cycles: an overview

At the moment of birth, each of the three biorhythm cycles is initiated and the cycles follow a fixed sinusoidal pattern throughout the life of an individual. The physical cycle P has a period of 23 days, the sensitivity (or emotional) cycle S has a period of 28 days and the intellectual cycle has a period of 33 days. Individuals with different birth dates will consequently have different composite biorhythm charts, although theory holds that the cycles of all individuals follow the same 23, 28 and 33 days natural biological rhythm. The calculation of an individual’s biorhythm at any given time requires first that the date being investigated be specified. The subject’s age in days, from the date of birth, up to, and including, the date of interest must next be determined (England and Naitoh, 1980). In this calculation individual biorhythm consideration should be given to regular leap years and centurial leap years. The equations for the natural biorhythm curves are as follows:

(a) physical biorhythm cycle: \( \sin \left( \frac{2\pi t}{23} \right) \)

(b) emotional biorhythm cycle: \( \sin \left( \frac{2\pi t}{28} \right) \)

(c) intellectual biorhythm cycle: \( \sin \left( \frac{2\pi t}{33} \right) \)

(d) intuitive biorhythm cycle: \( \sin \left( \frac{2\pi t}{38} \right) \)

where, \( t \) indicates the number of days since birth. Typical natural biorhythm cycles are shown in the following Figure 1.

Figure 1  Natural biorhythm cycles (see online version for colours)

(a) The physical biorhythmic cycle (23 days)

The physical cycles originate in muscle tissues or fibres. The physical cycle is from our masculine inheritance and affects our physical condition. During the plus side of the cycle (day 2 through day 11) our physical condition is in a charged state, we are full of optimism, our stamina is high, we need lots of movement, and physical work is easier. We feel more vigorous and have more vitality. Our endurance level is higher and this is a
time of activity for starting new tasks. Some doctors abroad believe that days 2 through 9 (in the plus half of the cycle) are the best days to have elective surgery. During the minus portion of the cycle (day 13 through day 23) we are in a recuperative recharging state and may tire more easily. This period is conducive to recuperation, we are less resistant to stress and physically active. This is not a good time for starting difficult or energy demanding tasks. Thommen (1973) has described that some athletes, depending on the state of other cycles and factors may have a slump during this time. Although a well trained athlete who has not over prepared could succeed at this time. This is not a ‘bad’ time. In fact it can be a good time to practice routine physical activities and ‘recuperate’. Thommen compares the physical cycle to a car battery and generator. The fully charged battery can spark the ignition to full power. When the battery has run down the generator switches in to charge the battery back to full power. The critical points of the physical cycle are at day 1 and day 12 1/2. We may be more prone to misjudge our physical energy or endurance while switching from one phase to the other. On critical days we must be more careful, more attentive, and should not hesitate to put off things which involve a lot of physical effort.

(b) The emotional biorhythmic cycle (28 days)

The emotional cycle governs the nervous system. It is due to the influence on nerve cells from one’s feminine inheritance and affects the level of emotion. During the high end of the cycle (day 2 to day 14) one is more inclined towards optimism and cheerfulness. Creativity, productivity, friendship, feelings, love and cooperation are favourably influenced. The positive phase brings optimism, joy, openness, tolerance, and self control. During the low end of the cycle (day 16 to day 28) your emotions are in a recuperative state, as explained by Hines (1998). You are more inclined to be irritable and negative. The negative side brings pessimism, withdrawal, bad moods and, sometimes, completely illogical sadness. The relative high and low of these two phases is definitely influenced by our general temperament. An excitable person will have a wider swing than a more sedate or calm person. The critical days are day 1 and day 15. Insurance and industrial statisticians in the USA and abroad have noticed a higher percentage of self caused accidents on these days. Drivers and other people needing to react quickly with sound judgement should be cautious on these days. According to Thommen (1973) there is something interesting about these critical days. Since the emotional cycle is 28 days long, exactly 4 weeks, day 1 and day 15 always fall on the day of the week that you were born. Every other week, this day is a critical day in your emotional cycle. If you do not know what day of the week you were born your bio-chart can tell you. Just look at the days when the emotional cycle is on the axis between plus and minus.

(c) The intellectual biorhythmic cycle (33 days)

The intellectual cycle was not discovered along with the physical and emotional cycle and it does seem to be less prominent than the latter two. Yet, it does have an influence. The intellectual cycle originates in the brain cells. When the intellectual cycle is in its high, plus phase (day 2 to day 16) one is more capable of absorbing new ideas and can think more clearly. Mental responses are more spontaneous and memory functions well according to Douglas and Francis (1976). In the positive phase we have maximum powers of concentration and our memory skills are high. We can adopt any situation and can make difficult decisions during this period. This is a good time for creative thought
and studying new ideas. During the low phase (day 18 to day 33) your capacity to think may be reduced. This may be a better time to rehearse and review known concepts. Practice of things known will facilitate storage into the mind and the sub-conscious. The critical points are at day 1 and day 17 1/2. On these days we should put off making important decisions.

2.1 Interpretation of biorhythm cycles

Biorhythmic study focuses on physiological, emotional and intellectual process and its forecasting. Biorhythm phenomena are observable human conditions which can be detailed and explained by biorhythms. Each cycle oscillates between a positive phase [0% to 100%] and a negative phase [-100% to 0%], during which bioelectric activity strengthens and weakens. Regarding the waveform in any of the three cycles, the positive period is thought to represent favourable conditions that are high performance intervals for intellectual function (I) or for physical coordination (P) of cycles. On the other hand the negative period is thought to represent a recharging phase. During the recharging phase it is believed that a person is inclined to tire more easily (P) become depressed or irritable more readily (s) and exhibit a lesser degree or acuity in the learning and decision making process. In the workplace, rail roads and airlines we have experimented the most with biorhythm. The Japanese and American pilots describe the most serious aircraft accidents due to biorhythms (Shaffer et al., 1978). He acknowledges, researching his pilot logbook, that his greatest errors of judgement occurred on critical days; but adds that being aware of one’s critical days and paying extra attention is sufficient to ensure safety (Khalil and Kurucz, 1977).

2.2 Accident prone zone/critical days

Critical days have been described as full of danger and difficulties. Accident-prone days are said to occur when one’s energy changes from the positive phase to the negative phase or vice versa. These days, also called critical days, are considered to be accident-prone because the body’s system is in the state of transition and is not stable. They are days of flux and high instability. This instability does not in itself cause accidents, but does apparently have a mild negative influence on performance, which may increase the danger. Critical days are not days when an accident will occur, but are a time when you will be more accident prone. John et al. (1977b) has represented the correlation of general aviation accidents with the biorhythmic theory and it is experienced as an accident-prone day. On these days the organism polarity is on state of flux and, therefore, the feedback process is highly variable. In this period the organism does not receive an immediate and accurate assessment of his capacity. Each accident case was analysed to determine whether or not the accident occurred on a biorhythmically critical day, as shown in Table 1. The data were also systematically evaluated for the existence of non-biorhythmic cycles. Accidents can be prevented if an individual is prevented from working in a hazardous situation on critical or accident-prone days.
Table 1  Accident prone days in percentage

<table>
<thead>
<tr>
<th>Accident prone day</th>
<th>24 h period</th>
<th>Expected accident prone days</th>
<th>48 h period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single physical (P)</td>
<td>7.5850</td>
<td>11.0107</td>
<td>13.0990</td>
</tr>
<tr>
<td>Single sensitivity (S)</td>
<td>6.1265</td>
<td>5.6465</td>
<td>10.3707</td>
</tr>
<tr>
<td>Single intellectual (I)</td>
<td>5.1383</td>
<td>7.3404</td>
<td>8.5827</td>
</tr>
<tr>
<td>Double (P) and (S)</td>
<td>0.5835</td>
<td>0.8470</td>
<td>2.1834</td>
</tr>
<tr>
<td>Double (P) and (I)</td>
<td>0.4894</td>
<td>1.1011</td>
<td>1.8069</td>
</tr>
<tr>
<td>Double (S) and (I)</td>
<td>0.3953</td>
<td>0.5647</td>
<td>1.4305</td>
</tr>
<tr>
<td>Triple (P) and (S) and (I)</td>
<td>0.0376</td>
<td>0.0847</td>
<td>0.3011</td>
</tr>
<tr>
<td>Total accident prone</td>
<td>20.3557</td>
<td>26.5951</td>
<td>37.7752</td>
</tr>
<tr>
<td>Incident prone</td>
<td>79.6443</td>
<td>73.4049</td>
<td>62.2248</td>
</tr>
</tbody>
</table>

2.3 Combined biorhythm cycles

The three-biorhythm cycles may be charted on one curve, as shown in Figure 1. The three rhythms are plotted independently and their relative positions will change from month to month. Combined biorhythm cycles illustrate several accident-prone days. Accident-prone day 1 shows a crossing of the physical cycle. At this point the sensitivity cycle is recharging, while the intellectual cycle is at a high. On the other hand, an accident-prone day illustrates a double-crossing of the zero axes or a double critical day. Similarly, three were crossing within the same day resulting in a triple critical day.

3 Causes of aircraft accidents

The correlation of occurrences of aircraft accidents to critical and negative phases of biorhythm cycles have been investigated by John et al. (1977a). Data from 880 accident cases involving US Air Force pilots were studied and added to 4278 previously reported cases. The data were tested by Chi-square analysis under the null hypothesis that there is no effect of biorhythm on aviation accidents. Under this hypothesis, the expected number of accidents occurring on critical days should be 179.13 for the US Air Force. The investigation of Sacher (1974a, 1974b) dealt with the problems of biorhythmic criticality and its influence on human error and accidents, based on data from 4346 naval aircraft mishaps in the Fiscal year 1968–1973. John et al. (2006) have calculated biorhythm for over 4000 pilots involved in general aviation accidents in 1972. Data were obtained from the fields of the National Transportation Safety Board. Data were analysed for correlation of aircraft accident occurrences with both biorhythmically critical days and with individual and multiple low or negative phases of cycle.

The causes of aircraft accidents in military aviation can be classified into direct and indirect causes.

3.1 Direct causes of aircraft accidents

Direct causes of aviation accidents (Scott et al., 2006) are directly responsible for the aircraft accidents. Direct causes are sub-classified as under:
3.1.1 Technical defects in aircraft

Technical defect indicates failure of some aircraft system while it is flying; for example, the chances of failure of one engine of a twin-engine aircraft system not coming down under carriage system. Technical defects create hazardous situations, which may lead to an aircraft accident (Kaushik et al., 1990). The crew should take proper steps to handle this hazardous situation and land the aircraft safely in the nearest aircraft field. The reliability of an aircraft system in which accidents are due to technical defects can be evaluated using Binomial Distribution.

3.1.2 Environment factors

Environment factors are the factors, which are beyond the control of pilot/crew/military aviation. Some of the typical environmental factors are as follows:

3.1.2.1 Bad weather conditions

Some of the aircraft in military aviation have to fly in bad weather conditions. For example, CB clouds create a hazardous environmental situation. CB clouds are charged clouds which jam the Gyro instruments in the aircraft, and severe updrafts and downdrafts, which are inherently present in the cloud throw the aircraft upwards and down-wards, till it is disintegrated. The best way to overcome this hazardous situation is to avoid flying into this cloud. The exact position of the CB clouds should be known to the pilot by weather radar and through the ground control.

3.1.2.2 Bird strike

Aircraft have to avoid bird strike during take off and landing. As the aircraft is flying at supersonic speed the birds act as missiles and can damage the aircraft. George (1974) has presented activities related to aircraft hazard due to bird strike at Charleston AFB, South Carolina, and studied a 500 square mile coastal area from 1 June 1971 to 1 June 1972. He presented a theoretical development for the calculation of binomial probability distribution functions for assessing the risk of bird hazards to aircraft using radar. Each distribution function has been studied to determine the maximum risk and the corresponding number of birds involved. The cumulative probability of bird strikes over an entire route can be determined by calculating the union of discrete cell probability sets.

3.1.2.3 Ricochets

Ricochet is an environment factor in military aviation. Ricochets occur when bullets are fired from an aircraft and get reflected. The reflected bullets may hit the same aircraft or one of the other aircraft flying in formation for bombing/target practice.

3.1.3 Human factors

Human errors are basic mistakes committed by the pilot/aircrew during flying. It was observed that most experienced pilots had committed the basic mistake of landing with the flaps up position, calling three greens when the under carriage lever
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is in the up position. These human errors can lead to a major aircraft accident unless they are controlled in time. It is rather difficult to understand why experienced pilots have committed such silly mistakes. Psychologists believe that such silly mistakes committed by experienced pilots may be due to some indirect causes, which affect the functioning of the pilot’s mind and interfere with his skill, which ultimately leads to such silly mistakes.

3.2 Indirect cause of aircraft accidents

The indirect cause is a factor which affects human performance, which can lead to aircraft accidents. An indirect cause is inter-action between skill and stress. The pilots acquire the skill of flying an aircraft through an intensive training for a minimum of three years. These experienced pilots have capabilities to overcome unfavourable environmental situations and even tackle technical defects, if any develop, during flying. The performance of these pilots while flying an aircraft is the result of interaction between skill and stress. Skill represents physical and mental capabilities, properly developed attitude, acquired knowledge about the aircraft and its operations, and the experience of flying. Stress is a feeling of hardship or tension caused by overpowering situations when the individual feels that his resources for dealing with them are inadequate. Stress is a part and parcel of human beings and is unavoidable. Pilots have to face stress. Pilots are subjected to two types of stresses.

3.2.1 Cumulative stress

3.2.1.1 Unusual life conditions

Unusual life conditions are unhappy family life, financial problems, and frequent transfers. A study by NATO reveals that cumulative stress loads of many such events in the immediate past predispose a person to psychosomatic, or purely physical, loss. Such cumulative stress leads to attention failure, error of judgement or forgetfulness.

3.2.1.2 Life style and temperament

Life style factors are

- over ambition
- constant worry
- perfection in every thing expected at every time.

Poor temperament of the pilot is one of the responsible indirect factors of the aircraft accidents.

3.2.1.3 Zero error factor

Modern aviation undoubtedly calls for a zero error factor, an inescapable requirement; some social scientists believe that it is impossible to achieve a zero error factor as a person is likely to commit a mistake some time or the other. Achievement of zero error factors in a particular field or in one’s over all activity, as has been seen, is not possible to achieve. What is needed is a very high degree of mental discipline and unwavering adherence to the specified parameters, but increasing sophistication in science and
technology leads to more and more closely structured organisations, bearing very little independence of action or thought to the individual. There is a known element in human beings because of which it is inherent to resist severe structuring and this is a strong pointer towards incidents/accidents where lack of flying discipline has been the primary cause. In advanced countries, the evolution of technology has been gradual and steady with the appropriate results. The individual in society could systematically acclimatise to the stress placed on him in the form of higher demands of mental discipline, and curb the general tendency or urge for independent action. On the other hand, in developing countries like ours, instead of gradual, technical evolution, we find an explosion of technology, just in the last two and a half decades. We have been suddenly exposed to very high levels of technology. The society or the individual did not have sufficient time to adjust to the constant demands of high technology. This is a basic cause of aberrations in flying discipline and this has been much in evidence in the early 1950s in the USAF despite having about 300 years of backup of growing technology, and later during the 1960s in the Royal Air Force. This is an important element, which must find its place in outdated modes of training. It would not be incorrect to state that the pilot could perhaps, what is generally known as, throw around the aircraft like a tempest or hurricane, but he could hardly afford to indulge even in a very small way and take liberties with high performance aircraft like the Jaguar, or the Mirage 2000 with F-16 class, though this aspect is emphasised adequately in training, right from beginning. It is a continuous wherein, though rigorous training we would achieve not only a very high degree of psychometric skills, but also developmental discipline, to create a safe flying environment.

3.2.2 Sudden stress

Pilots are subjected to sudden stress when they have to handle the following situations:

3.2.2.1 Technical defects in aircraft

The pilot is subjected to sudden stress when some aircraft systems fail in air. For example, failure of one engine of a twin-engine aircraft or failure of under carriage system not coming down when the switch is put down.

3.2.2.2 Cognitive factor

The cognitive factor is conflict, which takes place in a situation in which each one tries to establish an identity and wants recognition. Cognitive conflict is found to be predominant in modern military aviation and in the Air Force.

4 Statistical technique for biorhythmic analysis

In any Biorhythm research analysis it is necessary to scientifically demonstrate whether or not a relationship exists between biorhythm and human performance (Douglas and Francis, 1976). Hence, fundamental concepts in probability and statistical analysis have been applied to use the Gaussian distribution approach for biorhythmic analysis to prevent aviation accidents. Biorhythm has been reviewed in this paper. The probability of
occurrence of accident-prone days is 21.9%. This value is reduced to 20.4% by excluding multiple critical days. The probability of occurrence of single, double and triple critical days has been shown in Table 1. It is to be noted that the longer the cycle period the higher the probability of a zero crossing. Since the accident-prone periods for physical and intellectual cycles will alternately centre on midnight and noon for the adjutants, it is often difficult to accurately assign an accident to this biorhythm periods. It is therefore convenient to assess a 48 h period for alternate periods of physical and intellectual cycles. The expected percentages of occurrence of accident-prone days are presented in column 3 of table. It is found that in this case the probability of occurrence of accident-prone days is 26.6%, each biorhythm accident-prone period may also be analysed as a 48 h period. The 4th column of the Table shows the expected percentage of occurrences of accident-prone periods for a 48 h period. The expected occurrence of these accidents prone periods is 37.8%.

Carlos (2004) found that four principles are essential for hostage rescue mission success: surprise, intelligence, operation’s skill, and deception. These principles are derived from planning models used in special operations, personal experience, and an analysis of six historical case studies. The normal distribution curve, based on data available in the air force, has been designed. The area under the normal distribution curve represents the accident zone. Within this accident zone is that area of operation during which the performance demand exceeds the performance ability of the aircraft pilot. The incident-duration curve of aircraft accidents has been designed by Saket and Wg. Cdr. Kaushik (2005). The incident-duration curve has been assumed to be a straight line and increases with duration for reliability evaluation of the air-craft system.

5 Reliability analysis of the biorhythmic aviation accidents

Reliability of the aviation system is defined as the overall ability of the aircraft system to perform its function. Reliability theory, as an extension of probability theory, was first applied in the electronics, nuclear and space industries after world War-II, where high reliability was a requirement from these increasingly complex systems. Nowadays, reliability studies are performed in almost all engineering branches. This paper presents a new methodology for evaluation of the Probability of Accidents ($P_a$) based on the biorhythmic approach. The methodology has been developed in this paper using normal distribution curve of the accidents. Biorhythmic accidents have a continuous distribution function and have a Gaussian distribution for a specified time interval.

5.1 Gaussian distribution approach

The performance demand model of the pilots flying has been a Gaussian distribution for a specified time interval according to incident – duration curve (Arya et al., 2001).

$$f(P_v) = \frac{1}{\sigma \sqrt{2\pi}} e^{-\frac{(P_v - \mu)^2}{2\sigma^2}}.$$ (1)

The aggregate performance capacity model of the pilot of the air craft system has been approximated as Gaussian.
The failure probability \( P_F \) of the above performance demand and capacity models of the pilot can be written as follows:

\[
P_F = (1 - P_s). \tag{3}
\]

The success probability of the model \( P_s \) can be expressed as follows:

\[
P_s = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \frac{1}{2\pi \sigma_x \sigma_y} e^{-\frac{1}{2} \left( \frac{x^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} \right)} \, dx \, dy. \tag{4}
\]

After substitutions, equation (4) can be written as follows.

\[
P_s = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-0.5(x^2 + y^2)} \, dx \, dy. \tag{5}
\]

In the view of the above substitution (5) the success probability of the system can be written as follows using Gaussian distribution approach (Arya et al. 2001).

\[
P_s = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} e^{-0.5(x^2 + y^2)} \, dx' \, dy'. \tag{6}
\]

where,

\[
\beta = \frac{\bar{C} - \bar{P}_d}{\sqrt{\sigma_d^2 + \sigma_C^2}}. \tag{7}
\]

The limit \( \beta \) comes out to be independent of \( x' \). Further equation (6) can simplified as follows:

\[
P_s = \int_{-\infty}^{\beta} \int_{-\infty}^{\beta} e^{-0.5(x^2 + y^2)} \, dx' \, dy' = \frac{\beta}{\sqrt{2\pi}} e^{-0.5(x^2 + y^2)} d\beta = \phi(\beta) \tag{8}
\]

In fact \( \phi(\beta) \) is the success probability of the aircraft system and represents the area under the normal distribution curve having mean zero and standard deviation \( \int_{-\infty}^{\beta} \phi(\beta) = 1 \). Various curves based on equation (8) have been plotted using MATLAB simulation.

### 5.2 Failure probability evaluation approach

To evaluate \( \phi(\beta) \) the area under the normal distribution curve \( e^{-0.5\beta^2} \) has been evaluated using following steps (Arya et al., 2001).

\[
I_1 = \int_{-\infty}^{\beta} e^{-0.5\beta^2} \, dy, \quad I_2 = \int_{-\infty}^{\beta} e^{-0.5\beta^2} \, dy
\]

\[
I_1 \cdot I_2 = \int_{-\infty}^{\beta} \int_{-\infty}^{\beta} e^{-0.5(x^2 + y^2)} \, dx \, dy \tag{9}
\]
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\[ X = r \cos \theta \text{ and } Y = r \sin \theta \]

But \( I_1 = I_2 \)

So, \( I_1^2 = \int_{-\beta}^{\beta} e^{-0.5r^2} \cdot r \, dr = -\Pi \cdot e^{-\beta^2}. \)

So we get, \( P(f) = \sqrt{e^{-\beta^2} / 2} \)

\[ P_f = \int_{-\beta}^{\beta} \frac{1}{\sqrt{2\Pi}} e^{-0.5y^2} \, dy. \]  

(10)

This expression satisfies the Gaussian distribution approach of the pilot’s reliability evaluation. \( \varphi(\beta) \) is the area under the normal distribution curve having zero mean and standard deviation \([N(0, 1)]\) one from \(-\infty\) to \(\beta\) and this value can be conveniently obtained from standard tabulated data. Daily variation in the mental load or performance demand on the pilot can be accounted for by predicting the various demand levels \( P_{di} \) and the relative frequencies of accident occurrence of these levels are assumed to be \( L_0, L_1, L_2 \ldots, L_i \) and frequency of occurrence as \( \alpha_0, \alpha_1, \alpha_2, \ldots, \alpha_i \). For each demand level the probability of failure can be calculated and the overall probability of failure is given as

\[ P_f = \sum_i \alpha_i P_{fi}. \]

Various plots of \( P_f \) vs. \( \beta_f / P_f \) have been plotted in this paper. The curves presented here can be used as the standard curves for evaluating the pilot’s capacity.

5.3 Safety factor concept and peak demand considerations

The probability distribution function of the capacity of the pilot has been obtained by Gaussian distribution, as earlier. Further, it has been obtained that peak performance demand dominates over low-level loading, whereas the probability of failure under low load level conditions is negligible. \( P_{d_{\text{max}}} \) is the peak performance loading/demand on the pilot. The safety factor ‘\( S \)’ is defined as:

\[ S = C / P_{d_{\text{max}}}. \]

(11)

It is obvious that the pilot’s ability to fly/flying capacity ‘\( C \)’ has normal distribution and \( S \) is a random variable. Since \( P_{d_{\text{max}}} \) has been considered to be constant, the safety distribution function ‘\( S \)’ will also be normal and is given as follows (Arya et al., 2001).

\[ f_S = \frac{P_{d_{\text{max}}}}{2\pi \sigma_c} e^{-0.5 \left( \frac{S - \bar{S}}{\sigma_c} \right)^2}. \]

(12)
The mean safety factor and standard deviation of the safety factor is given as:

$$\bar{S} = \frac{C}{P_{d,\text{max}}} \quad \text{and} \quad \sigma_s = \frac{\sigma}{P_{d,\text{max}}}.$$ 

The probability of the performance failure is given as under:

$$P_e = \int \frac{P_{d,\text{max}}}{\sqrt{2\pi}\sigma_s} e^{-\frac{(t - \bar{C}/P_{d,\text{max}})^2}{2\sigma_s^2}} ds = \Phi\left(1 - \frac{\bar{C}}{P_{d,\text{max}}}, \frac{\sigma}{P_{d,\text{max}}} \right).$$

(13)

Failure probability $P_e$ vs. $\bar{C}/P_{d,\text{max}}$ curves have been plotted using MATLAB simulation. There are the standard curves for evaluating the performance capacity of the pilot based on safety factor concept and peak load considerations.

5.4 Performance evaluation based on LOLP using Simpson’s 1/3rd rule

LOLP is one of the most commonly used indices for planning the performance capacity of the pilot. This index is generally obtained by combining the performance model with a demand model. All types of composite reliability indices i.e., loss of load probability, and accident frequency have been assessed, not only for the overall aircraft system but also for single component and aircraft pilots. Failure probability has been evaluated with a more realistic model as an incident – duration curve. A stepped incident-duration curve has been considered for aircraft system reliability evaluation using Simpson’s 1/3rd rule. In the following expression, 100 small steps have been considered in the daily incidence – duration curve. The performance model adopted is the normal distribution function and the evaluation is based on the maximum available average performance capacity of the pilot. The probability of the performance demand exceeding the performance capacity (LOLP) of pilot using stepped incidence – duration curve can written as follows:

$$LOLP = \int_0^{100} \left[ \frac{P_{d,\text{max}}}{\sqrt{2\pi}\sigma_s} \right] \int_0^{100} e^{-\frac{(t - \bar{C}/P_{d,\text{max}})^2}{2\sigma_s^2}} dt$$

(14)

Putting, $\frac{C - \bar{C}}{\sigma} = Z$.

The LOLP expression of (14) can be expressed as:

$$LOLP = \int_0^{100} \left[ \frac{P_{d,\text{max}}}{\sqrt{2\pi}\sigma_s} \right] \int_0^{100} e^{-\frac{(t - \bar{C}/P_{d,\text{max}})^2}{2\sigma_s^2}} dt = \int_0^{100} \frac{P_{d,\text{max}}}{\sqrt{2\pi}\sigma_s} \varphi\left(\frac{P_{d,\text{max}} - \bar{C}}{\sigma_s}\right) dt.$$

(15)

LOLP of the composite aircraft system can be evaluated by above methods of area evaluation for any step of the incident – duration curve (Arya et al., 2001). Simpson’s
1/3rd rule has been used to evaluate the LOLP of the pilot of the aircraft system. Reliability of aircraft operation, or success or failure probability of the aircraft system based on biorhythm theory has been evaluated using Simpson’s 1/3rd rule, considering small steps of durations and various operation periods of aircraft systems.

6 Results and discussion

The failure probability due to the biorhythmic effect on the pilot of the aircraft system, as explained earlier, has been evaluated assuming that the following data are available. The mean performance ability of the pilot to fly ($P_a$) in percentage and standard deviation data are given in Table 2.

<table>
<thead>
<tr>
<th>$P_a$ (%)</th>
<th>90</th>
<th>89</th>
<th>88</th>
<th>87</th>
<th>86</th>
<th>85</th>
<th>84</th>
<th>83</th>
<th>82</th>
<th>81</th>
<th>81.5</th>
<th>80.1</th>
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</thead>
<tbody>
<tr>
<td>$\sigma_a = 5$</td>
<td>4.50</td>
<td>4.45</td>
<td>4.40</td>
<td>4.35</td>
<td>4.30</td>
<td>4.25</td>
<td>4.20</td>
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<td>4.005</td>
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<td>$\sigma_a = 10$</td>
<td>9.0</td>
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<td>8.7</td>
<td>8.6</td>
<td>8.5</td>
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<td>8.3</td>
<td>8.2</td>
<td>8.1</td>
<td>8.05</td>
<td>8.01</td>
</tr>
<tr>
<td>$\sigma_a = 15$</td>
<td>13.5</td>
<td>13.35</td>
<td>13.2</td>
<td>13.05</td>
<td>12.9</td>
<td>12.75</td>
<td>12.6</td>
<td>12.45</td>
<td>12.30</td>
<td>12.15</td>
<td>12.07</td>
<td>12.02</td>
</tr>
</tbody>
</table>

The probability of accident/failure probability of the aircraft’s pilot ability to fly due to biorhythmic effects at mean performance demand ($P_d$) 80% has been evaluated using equation (9). The biorhythmic accident probability ($P_ac$) at different conditions of pilots ability to fly is given in Table 3.

<table>
<thead>
<tr>
<th>$P_a$ (%)</th>
<th>$P_ac$ at $\sigma_a = 5%$</th>
<th>$P_ac$ at $\sigma_a = 10%$</th>
<th>$P_ac$ at $\sigma_a = 15%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>90.00</td>
<td>0.5485</td>
<td>0.6539</td>
<td>0.7637</td>
</tr>
<tr>
<td>89.00</td>
<td>0.5668</td>
<td>0.6788</td>
<td>0.7810</td>
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<tr>
<td>88.00</td>
<td>0.5901</td>
<td>0.7033</td>
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</tr>
<tr>
<td>87.00</td>
<td>0.6091</td>
<td>0.7327</td>
<td>0.8301</td>
</tr>
<tr>
<td>86.00</td>
<td>0.6539</td>
<td>0.7643</td>
<td>0.8483</td>
</tr>
<tr>
<td>85.00</td>
<td>0.6949</td>
<td>0.7981</td>
<td>0.8707</td>
</tr>
<tr>
<td>84.00</td>
<td>0.7451</td>
<td>0.8336</td>
<td>0.8897</td>
</tr>
<tr>
<td>83.00</td>
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<td>0.8707</td>
<td>0.9207</td>
</tr>
<tr>
<td>82.00</td>
<td>0.8632</td>
<td>0.9091</td>
<td>0.9443</td>
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<tr>
<td>81.00</td>
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</tr>
<tr>
<td>81.50</td>
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<td>0.9801</td>
<td>0.9880</td>
</tr>
<tr>
<td>80.10</td>
<td>0.9923</td>
<td>1.0</td>
<td>1.0000</td>
</tr>
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</table>

The graphs between probability of accident by aircraft pilot due to biorhythm and mean performance ability are shown in Figures 2 and 3. The distribution functions for both performance ability to fly and performance demand on the aircraft’s pilot have been
obtained to be normal. From Figure 2, the performance demand of the aviation system is constant at 80% and performance capability of pilot increases gradually. At different performance abilities of the pilot, considering biorhythmic effects, the failure probability of the system has been evaluated. The failure probability of the aircraft due to the biorhythmic effect of the pilot decreases with the increase in the aircraft pilot’s capability. At the moment of equal performance ability and demand, success or failure probability becomes equal to 50%. If performance demand exceeds the performance capability of the pilot due to biorhythm, there is 100% probability for the aviation accident.

Failure probability of the aircraft system due to biorhythmic effects has been evaluated using safety factor concept and shown in Figure 2. At constant performance demand of the aircraft system, the safety factor increases with the performance ability of the pilot. This plot indicates that the failure probability decreases with the increasing value of the performance safety factor. At constant performance ability and increasing performance demand, the failure probability of the aviation system increases and curves cut each other at 0.5. At this point, success and failure probabilities become equal to 50%. If demand increases with the biorhythmic ability of the pilot, no one can prevent the aircraft system from accident.

Figure 2  Failure probability (aviation accident chances) vs. performance capability of the aircraft pilot (see online version for colours)
7 Conclusion and future work

It has been demonstrated that whenever the pilot demand exceeds the pilot performance ability, the probability of aircraft accident increases. Biorhythm plays a vital role in increasing the internal demand of the pilot and diminishes pilot ability. The failure probability of the system due to the pilot’s inability has been described by various plots, as shown in the Figures 2 and 3. Failure probability of the aircraft system decreases with increase in the standard deviations of the performance ability of the pilot. Serious aircraft accidents, to the tune of 70–80%, are associated with the influence of human error. These are considered to be most critical, when the functional systems of aircraft fail and when the pilot is exposed to adverse factors. Because the pilot’s psyche and physiological factors affect his performance in air, errors are likely to be committed.

Among the factors which lead to disturbances in the pilot’s psyche could be personal living experiences and events, various psychological factors, biorhythm, reactions to emergency situations, training, machine factors which are largely technical in nature and environment, etc. To study physical, emotional and intellectual cycles when an aircraft pilot is prone to accident, selection should be made of pilots who are not prone to accidents on these days. Training should also be imparted to such selected pilots and rejecting those who cannot keep their cool during emergencies. The study of the behavioural aspects, man-machine interface and reliability improvements will help to reduce the number of aviation accidents. Reliability analysis of the aviation system, considering the biorhythmic effects of typical biorhythm cycles at constant performance ability of the pilot with variable biorhythmic demand, has been proposed for future research work.
Acknowledgements

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References


Probabilistic approach for biorhythmic analysis


**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( P_{ac} )</td>
<td>Probability of accident</td>
</tr>
<tr>
<td>( P_a )</td>
<td>Performance ability of aircraft pilot to fly</td>
</tr>
<tr>
<td>( \alpha_i )</td>
<td>Frequency of accident occurrence</td>
</tr>
<tr>
<td>( P_f )</td>
<td>Failure probability of aircraft</td>
</tr>
<tr>
<td>( P_s )</td>
<td>Success probability of the aircraft</td>
</tr>
<tr>
<td>( S )</td>
<td>Safety factor of performance</td>
</tr>
<tr>
<td>( \phi(\beta) )</td>
<td>Area under normal distribution curve and success probability</td>
</tr>
<tr>
<td>( P_d )</td>
<td>Performance demand of aircraft pilot to fly</td>
</tr>
<tr>
<td>( P'_a )</td>
<td>Average or mean performance ability of the pilot to fly</td>
</tr>
<tr>
<td>( P'_d )</td>
<td>Average or mean demand of pilot ability to fly</td>
</tr>
<tr>
<td>( \sigma_d )</td>
<td>Standard deviation of performance demand</td>
</tr>
<tr>
<td>( \sigma_a )</td>
<td>Standard deviation of performance ability</td>
</tr>
</tbody>
</table>