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# Predication of Flutter Phenomenon in Supersonic Vehicles at Relativistic Speed

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### Abstract

This article describes the aeroelastic flutter phenomenon at ultra-speed limits. Flutter initiates when the air-flow speed is over a certain flutter onset speed and the air-flow direction is nearly perpendicular to the moving body. It is the oscillatory instability in a potential air-flow, in which neither separation nor strong shocks are involved, which is essentially the continued and increasing oscillation of a moving body that is sustained only by the movement of a fluid over it, at a constant speed. It is important to understand the cause and effects of ultra-high speed to get a more accurate sense of how to prevent flutter from occurring during traveling at high speeds. At fairly constant air-flow speed the moving body was pushed in to aeroelastic phenomenon based on its dynamic and aerodynamic characteristics. Mechanical engineers are familiar with forced and resonance characteristic of moving systems at high speeds, but usually not with relativistic effects of motion at ultra-high speeds. In the real world, there exists the content of the principle of relativity, which is one of the basic postulates of the special theory of relativity. One of the most surprising features of special relativity is that a number of statements and results which we usually think to be absolute turn out to be observer-dependent. In particular, statements about space and time, distances and duration turn out to be relative. Similarly, temporal duration depends on the observer. This relativistic effect is called time dilation. Summarized briefly: Moving clocks are slower than stationary ones. A bit more precisely: An observer on station A measures time using his on-board clock. Station B, passing A at high speed, has an exact copy of A's clock on board. Yet, from the point of view of A, the clock in station B runs more slowly than his own. In this paper, we try to study length time of starting moment of flutter at ultra-relativistic limits with relativistic theory which determine and measure various quantities related to the velocities of observers when time is dilates.

### Keywords

Ultra-High Speed, Supersonic Vehicle, Relativistic Speed, Lorentz Invariant

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## 1. Interdiction

Self-oscillation is the generation of a periodic motion by an act on objects or body. If the source of power related to the moving objects, the self-oscillation will be created on body [1-6]. Natural phenomena such as pulsar supernova, pulsation of stars and also the heartbeat are the familiar self-oscillation phenomena. The flutter can be diagnosed as instability periodic motion of the moving object and then the oscillation amplitude of periodic motion grows exponentially with time. Therefore, the study of flutter is to a large extent of the theory of linear and nonlinear vibration, a subject which has been much more developed in engineering than in theoretical physics [5-7]. But, in ultra-high speeds, only physician can very carefully describe and find Lorentz invariant that is very important in determination characteristic and dynamic parameters for supersonic vehicles and modern high technology equipment. Properties and structure constants such as natural frequencies can change in every structure under the influence of specific type of aerodynamic forces and this change can be made strong

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instabilities that cannot be prevented even by re-entry increasing the reliability of the design. This destruction has been created due to a specific force and this value of force is created because of a specific relative velocity of air-flow that is called flutter [7-10] (aeroelasticity) phenomenon. One of the famous collapses is Tacoma Narrows Bridge. As we know self-oscillation applies to moving objects like wind turbine, airplane, blades, etc. On the other words, aeroelasticity is the study of the effect of the aerodynamic forces on elastic moving bodies. Here we try to describe specific situation that involves with ultra-high speed. Thus, we should lookout to the situation using relativistic equation in the space-time [11-14]. One of the interesting and important issues in flutter is the instability of moving object in air-flow because the aerodynamic forces increase quickly with the air-flow speed. There may be a critical air-flow speed at which the moving object becomes dynamically unstable. Such dynamic instability may cause much more destruction of the moving object in ultra-high speed than low speed. Self-oscillation is also known as, vibration, self-excited, and in the mechanical engineering literature it is known as flutter phenomenon is one of the main purposes in theoretical and engineering physics. The main approach in this study is that we will focus on the theoretical description of ultra-high speed. In this limit the Newton invariant could not be useful. So, a major problem that in this article is interesting for us is the flutter of rockets, ultra-high speed airplane, hypersonic glide vehicle, etc. We give an explanation for the onset of induced flutter in a hypersonic object. Our description accounts for the physical mechanisms at ultra-high relativistic limit that allows us to predict a critical time for the flutter by using relativistic motion characteristics, i.e. the general relativistic theory.

## 2. Moving Object at Ultra-High Speed

As we know the theory of four dimensional space-time is quite different from the theory of space and time, and also the Euclidean geometry of ordinary three dimensional spaces. The theory of space-time is relativity theory. It is seen to be a theory of the geometry of the single entity, 'space-time', rather than a theory of space and time [12-14]. The main idea of space-time is the coordinates of an event have transformation properties analogous to space and time for ordinary three coordinate vectors that involve with a time coordinate. We will consider each event $E$ occurring in space-time coordinates:

$(x\ y,z,t)$ in frame of reference $K$ and $(x',y',z',t')$ in the other inertial frame coordinates $K'$ (Fig. 1)[15, 16].

Relativity theory is the major theory on which modern technology and modern physics are based. This theory is general principles in moving which all specialized theories are required to satisfy and apply to all physical systems that move at ultra-high speeds. The role of relativity appears to be that of specifying the properties of space-time that all physical processes take place. The principles of relativity are: a) All the laws of physics are the same in every inertial frame of reference. This postulate implies that there is no experiment whether based on the laws of mechanics or the laws of electromagnetism from which it is possible to determine whether or not a frame of reference is in a state of uniform motion, b) The speed of light ($c = 299792458\ m/s$) is independent of the motion of its source. On the mathematical meaning we can say that the laws of physics are expressed in terms of equations, and the form that these equations take in different reference frames moving with constant velocity with respect to one another can be calculated by using transformation equations, which require that the transformed equations have exactly the same form in all frames of reference, in other words that the physical laws are the same in all frames of reference. In order to describe the moving object at ultra-high velocity, determination the geometrical properties of space-time four coordinate, is probably useful. Therefore, we should make use of the constancy of the speed of light and derive the general form that the transformation law must take place.

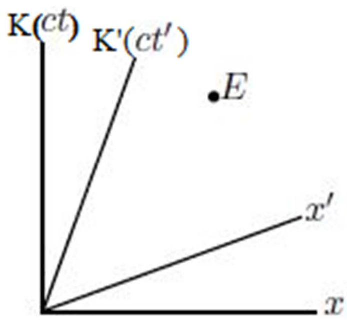


**Figure 1.** Space- time axes for two different reference frames.

In theoretical field of physics all objects that move with speed near the speed of light have a specific's motion equation and their dynamical description of motion should be based on the relativistic theory. Thus, hypersonic airplane include in this category. Hypersonic object is an object that travels at 4 up to 24 times faster than the speed-of-sound and in the theoretical and mechanical physics it considers as an ultra-high object ($v{\sim}10^{-5}c$) [18]. Therefore, hypersonic object can be an ultrasonic airplane, ultrasonic missile, or ultrasonic spacecraft, supersonic combustion ramjet, scramjet, and re-entry vehicle[1]. So, the aeroelasticity (flutter) is the main source of instability in structures which are subjected to

1 A re-entry vehicle is a spacecraft that travels through space and re-enters the atmosphere of a planet.

aerodynamic forces in the most of hypersonic structures, specially with thin and relatively long segments like small wings or blades. As we told above one of the major reasons of instability are the vibration [19-24] of the moving body and also the speed of object. To predicate the occurring moment of flutter in the hypersonic objects we study relativistic combination of space-time at ultra-high speeds. In the theoretically method, relativistic theory is employed to study the occurring moment of the flutter phenomena. Now, we describe space-time coordinate relation in relativistic limit [25-26]. As we know, Newtonian mechanics gives an excellent description of motion, but when the object travels very fast, we should use new motion equations, i.e., the Einstein theory that is called special relativity [9, 10]. The effect appears when the speed of moving body or object becomes comparable to the speed of light in the vacuum (*c = 299792458 m/s*). In the inertial frames $K'$ and $K$ coordinate systems that move with relative speed v to each other for simplicity, we'll start by using the direction $x$ which is parallel to the direction of motion. Both inertial frames come with Cartesian coordinates: $(x', t')$ for $K'$ and $(x, t)$ for $K$. As we know, relation between space and time base on Lorentz invariant:

$$\begin{cases} x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}} \\ y' = y \\ z' = z \\ t' = \frac{t - xv/c^2}{\sqrt{1 - v^2/c^2}} \end{cases} \tag{1}$$

Therefore, the most important achievement of the Lorentz transformation is relation of time in two coordinate systems. Consider an object placed at rest in a frame of reference $K$ at some point $x$ on the $x$ axis and suppose that this frame is moving with a velocity $v$ relative to some other frame of reference $K'$. The time interval between two events at $K'$ and the exact event at $K$ can be determined. Thus the time interval between events in $K$ is longer than in $K'$. It means that in the frame of reference $K$ the time is running slow. It appears from $K$ that time is passing more slowly in $K'$. Hence, after a series of mathematical transformations using equations in (1) we can find from (1) speed in moving space-time coordinate [9, 10]:

$$\Delta t' = \frac{\Delta t}{\sqrt{1 - v^2/c^2}} \tag{2}$$

or

$$\Delta t > \Delta t' \tag{3}$$

This is the phenomenon of time dilation that we will use to describe how one can predicate events at ultra-high moving space-time. Now, we suppose that an object has a velocity $v$ relative to a frame $K'$ and velocity of this object that measure in the frame of reference relative to a frame $K$ moving with a velocity $u$ relative to a frame $K'$ (Fig. 2).

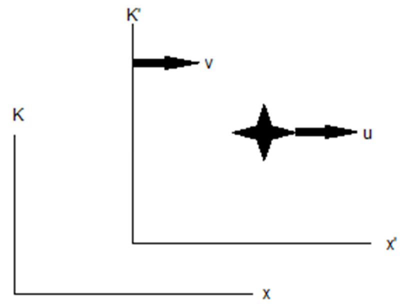


**Figure 2.** The inertial frames $K'$ and $K$, moving with relative speed $v$.

The moving object has the coordinate $x'$ at time $t'$ in $K'$ and has the coordinate $x$ at time $t$ in $K$. On the other words, if the observer in $K$ measures an object moving along the $x$ axis at speed $u$, then the observer in the $K'$ coordinate system that moving at speed $v$ in the $x$ direction with respect to $K$, will measure the object moving with speed $u'$ where from the Lorentz transformations (1):

$$u' = \frac{u - v\Delta t}{1 - uv/c^2} \tag{4}$$

and

$$u = \frac{u' + v}{1 + u'v/c^2} \tag{5}$$

In low speed both u and v are small with respect to the speed of light and we will recover

$$u' \cong u - v \tag{6}$$

the intuitive Galilean transformation of velocities. If objects moving with ultrasonic speed βc, we can determine delay time as follow:

$$\Delta t = \Delta t' \sqrt{1 - \beta^2} \tag{7}$$

and one may predicate the exact delay time in space-time coordinate when the flutter will be happened in moving space-time coordinate.

## 3. Flutter Description

The interaction between inertial forces, structural forces and aerodynamic force can cause several undesirable phenomena like flutter (dynamic aeroelastic phenomenon), divergence (static aeroelastic phenomenon) and vortex-induced vibration (unsteady aerodynamic phenomena) and limit cycle oscillations (nonlinear aeroelastic phenomenon), which we focus on the flutter phenomenon in the frame work of relativity theory. Flutter is the study of the interaction of inertial, structural and aerodynamic forces on the moving objects. If a moving object gives an initial disturbance, it starts to oscillate, in other words the motion will be grown to infinity. Therefore, equation of motion for the moving object will be the form

$$\ddot{q}\omega^2(t)q = 0 \tag{8}$$

where $\omega^2(t)$ is a periodic function and v is angular frequency. Analytic solutions equation (8) can be obtained only by approximation as follow:

$$\omega^2(t) = \omega_0^2(1 + aCos(\alpha t)) \tag{9}$$

If $a$ is small, strongest oscillations are seen to grow exponentially in time if the angular frequency is close to $2\omega_0$. This is the phenomenon of parametric resonance that resembles self-oscillation (flutter). The flutter condition occurs as a harmonic motion and the moving object will be unstable under the wind loading whose velocity is greater than or equal to the critical wind velocity. The prediction of flutter is an important area of modern technology. Therefore, in order to predicate event time, it is better to understand oscillation theory in the space-time coordinate for supersonic vehicles that presented in the above paragraph. Therefore, aeroelasticity's dynamic instability is characterized by critical speed. With increasing speed of moving object the air-flow state becomes very critical (Table 1.).

**Table 1.** The velocity range of sound speed.

| Speed limit | Range (km/h) | α-respect ratio to sonic | β- respect to light *10$^{-5}$ |
|---|---|---|---|
| Sonic | 1236 | 1 | 0.114 |
| Hypersonic | 6150- 12300 | 5:10 | 0.114-1.14 |
| High hypersonic | 12300- 30740 | 10:24 | 1.14-2.84 |
| Ultrasonic | More than 30740 | >24 | >2.84 |

For hypersonic moving objects, flutter response of the structure interacts with the air-flow, resulting in complex situations like vibrations cause alternating lift off and reattachment of the layer (resultant of the aerodynamic forces into a moving object is generally shown as the lift and drag forces). To describe flutter we should two types of movements in relation with the space-time coordinate of moving object. If the observer in the earth measures an object moving along the x axis at ultra-high speed v (hypersonic, high hypersonic) [11], and the observer measure oscillation in the moving object at speed u that is the occurring moment of flutter phenomenon in the x direction with respect to the earth so observer in the K′ will measure the moving object's oscillation at moment $t'$ with speed u′. Therefore, using equation (2), we can determine delay time when flutter will be happened in the K′ coordinate system. If objects moving with ultrasonic speed βc, so we can determine delay time as follow:

$$\Delta t' = \frac{\Delta t}{\sqrt{1-{(\beta c)^2}/{c^2}}} \approx 1.11\Delta t \tag{10}$$

On the other hands, two events (flutter) happening in two different space time that occurs simultaneously in the reference frame of one inertial observer K, may occur non-simultaneously in the reference frame of another inertial observer K′. The time lapse between two flutters in K and K′ is not invariant from one observer to another, but is dependent on the relative ultrasonic speeds of the observers' reference frames. Equation (6) shows that the time ($\Delta t'$) in the frame in which the object is moving (K′), is longer than the time ($\Delta t$) in the rest frame K. Time dilation explains a predication time that flutter will be occurred.

## 4. Conclusion

Flutter involves the study of the interaction between aerodynamic forces and elastic forces. The flexibility of the modern supersonic aircraft makes aeroelastic study an important aspect of aircraft design and stability verification procedures. The body torsional divergence and the flutter are the two major aeroelastic issues considered in supersonic vehicles. The flutter is an aeroelastic instability characterized by sustained oscillation of supersonic structure arising from interaction between elastic, inertial and aerodynamic forces acting on the moving body at ultra-high speed. At some critical speed, known as the flutter speed, the supersonic structure sustains oscillations following some initial disturbance. Below this flutter speed the oscillations are damped, whereas above it any one of the modes becomes important and instability oscillations will be occurring. Nowadays requirement of the growth in hypersonic and ultra-high speed vehicle safety, the fields of aerocosmic and aeroelastic science play a vital role. Flutter is one of the dynamic aeroelastic problems in the moving object upper than 24 times of sonic speed, it mainly occurs at lifting surfaces when the ultra-high vehicle cruises at very high speeds. At relatively low speeds, the torsional stiffness of the plate object is enough to counteract the twisting. However, the variation in flutter frequency causes the instability motion on supersonic vehicle. Therefore, the body displacement against the flow field plays a vital role in dynamic stability analysis. In order to maintain the supersonic object stability in ultrahigh speed, predication's time in occurring flutter can be determined in relativistic limit. The main focus of this study is to merge relativistic equation of motion in mechanical engineering science and determination of predication flutter's moment.

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