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MIRCE Mechanics Analysis of the Flight 1549

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Summary

The main objective of Mirce Mechanics is the understanding of mechanisms that generate positive and negative functionability events, which cause the motion of a system through corresponding functionability states. Hence, this paper addresses the mechanism of the collision between birds and flying objects, commonly know as a bird strike. This is typical example of the overstress mechanisms where a huge amount of kinetic energy is generated by the collision of both flying objects. Consequently, the main purpose of this paper is to analyse mechanisms of the motion of the USAir A320 through functionability states caused by the kinetic energy generated by the collision with a flock of Canadian Geese during the flight 1549, on 15th January 2009, in New York. The consequences of the motion on the fuselage and engines are analysed and presented here.

Key words: *Mirce Mechanics, functionability states, functionability events, failure mechanisms, aircrafts, biological materials.*

1. INTRODUCTION

Aerospace Engineering is the primary branch of engineering concerned with the research, design, development, construction, testing, science and technology of aircraft and spacecraft. It deals with the design, construction, and study of the science behind the forces and physical properties of aircraft, rockets, flying craft, and spacecraft. The field also covers their aerodynamic characteristics and behaviours, airfoil, control surfaces, lift, drag, and other properties.

The main scientific body of knowledge used in aerospace engineering is aerodynamics (from Greek □ήρ aer (air) + δυναμική (dynamics). It is a branch of dynamics concerned with studying the motion of air, particularly when it interacts with a solid object, such as an airplane wing. Formal aerodynamics study in the modern sense began in the eighteenth century, although observations of fundamental concepts such as aerodynamic drag have been recorded much earlier. Most of the early efforts in aerodynamics worked towards achieving heavier-than-air flight, which was first demonstrated by Wilbur and Orville Wright in 1903. Since then, the use of aerodynamics through mathematical analysis, empirical approximations, wind tunnel experimentation, and computer simulations has formed the scientific basis for ongoing developments in heavier-than-air flight and a number of other technologies.

While, aerodynamics is the scientific foundation of the functionality performance of aircraft, Mirce Mechanics: is a scientific theory of the functionability[1] performance of maintainable systems, including aircraft. Its axioms, mathematical formulas, rules and methods enable accurate predictions of a system's measurable functionability performance characteristics like reliability, punctuality and others to be made with probabilistic regularity [1].
From the Mirce Mechanics point of view, at any instant of time a system can be in one of the following two functionability states [2]:

- Positive Functionability State (PFS) is the state in which a system is being able to deliver functionality (function, performance and attributes),
- Negative Functionability State (NFS) is the state in which a system in not being able to deliver functionality.

Consequently, the life of a maintainable system could be considered as motion of system through functionability states, which is governed by the occurrence of functionability events, which are classified as:

- Positive Functionability Events (PFE) which cause the change of transition from NFS to PFS,
- Negative Functionability Events (NFE) which cause the transition from PFS to NFS.

The main objective of Mirce Mechanics is the scientific understanding of mechanisms that generate positive and negative functionability events. Hence, this paper addresses the mechanisms that cause the occurrence of NFE resulting from the collision between birds and flying objects, commonly know as a bird strike. This is a typical example of the overstress mechanisms where a huge amount of kinetic energy is generated by the collision of both flying objects. Consequently, the main purpose of this paper is to analyse the propagation of the collision generated kinetic energy through the fuselage and the engines of the aircraft and to assess the consequences of the NFE that occurred on the 15th January 2009 when a flock of Canada guesses collided with a USAir Airbus A320 in New York, USA.

2. THE USAIR FLIGHT 1549

On the 15th January 2009, the US Airways flight 1549, which originated from LaGuardia Airport (LGA), New York City, at 15.25 Eastern Standard Time, was en route to Charlotte Douglas International Airport, Charlotte, North Carolina. An Airbus Industrie A320-214 experienced an almost complete loss of thrust in both engines after encountering a flock of birds. At the time of the collision the aircraft was about 4.5 miles north-northwest of the approach end of runway 22 at LGA and about 9.5 miles east-northeast of the approach end of runway 24 at Teterboro Airport (TEB) New Jersey, New York.

Approximately, 60 seconds after the bird strike, it was evident to the flight crew that landing at an airport may not be an option, and, at 15.28:11, the captain reported to Air Traffic Control (ATC) that he did not think they would be able to land at LGA. Given the aircraft's airspeed, altitude, and position, Hudson River that flows through the centre of New York would be the best and safest landing option, from his point of view.

[1] Functionability, n, ability of being functional, Knezevic, J., Reliability, Maintainability and Supportability – A probabilistic Approach, Text and Software package, pp. 291, McGraw Hill, London 1993. ISBN 0-07-707691-5

Within seconds after the ditching on the Hudson River, the crewmembers and passengers initiated evacuation of the aircraft. All of the 150 passengers, including a lap-held child, and 5 crewmembers evacuated the aircraft via the forward and over-wing exits. During that process one flight attendant and four passengers were seriously injured, and the aircraft was substantially damaged [3].

3. BIRD STRIKE AS A NEGATIVE FUNCTIONABILITY EVENT

The onset of the jet age revolutionised air travel, but magnified the bird strike problem. Early piston-powered aircraft were noisy and relatively slow. Bird strike could usually avoid these aircraft, and strikes that did occur typically resulted in little or no damage. However, modern jet aircraft are fast and relatively quiet, and their engine fan blades are often more vulnerable than propellers to bird strike damage. When turbine-powered aircraft collide with birds or other bird strike, serious structural damage and engine failure can occur.

It basically comes down to the physics equation for kinetic energy:, which is proportional to mass times velocity squared. For example, when a plane is taking off, it is going 275 km/h and accelerates to several hundred km/h. At the take off fan blades in engines are rotating around 3,000 to 4000 rotations per minute, while the tips of those turbofan blades are reaching the speed of sound or greater. When a bird hits one of those fan blades, there's a tremendous energy transfer from the bird to the engine, and that's basically why a bird can cause serious damage to an aircraft engine.

According to [4] the number of bird strikes annually reported in the USA has increased 5.8-fold from 1,851 in 1990 to a record 10,726 in 2012 (131,096 strikes for 1990–2012). Although the number of reported strikes has steadily increased, the number of reported damaging strikes has actually declined from 764 in 2000 to 606 in 2012.

From 1990–2012, about 41 percent of bird strikes with commercial aircraft occurred when the aircraft was at 0 feet above ground level (AGL), 72 percent occurred at 500 feet or less AGL, and 92 percent occurred at or below 3,500 feet AGL. Less than 1 percent of bird strikes occurred above 9,500 feet AGL. Above 500 feet AGL, the number of reported strikes declined consistently by 34 percent for each 1,000-foot gain in height. The record height for a reported bird strike involving a commercial aircraft in USA was 31,300 feet AGL [4].

Strikes occurring above 500 feet AGL had a greater probability of causing damage to the aircraft compared to strikes at 500 feet or less. Although only 28 percent of the reported strikes were above 500 feet AGL, these strikes represented 43 percent of the damaging strikes [4].

The aircraft components most commonly reported as struck by birds from 1990–2012 were the nose/radome, windshield, engine, wing/rotor, and fuselage. Aircraft engines were the component most frequently reported as being damaged by bird strikes (30 % of all damaged components). There were 14,322 strike events in which a total of 15,013 engines were reported as struck (13,656 events with one engine struck, 647 with two engines struck, 13 with three engines struck, and 6 with four engines struck). In 4,069 damaging bird-strike events involving engines, a total of 4,206 engines were damaged (3,935 events with one engine damaged, 132 with two engines damaged, 1 with three engines damaged, and 1 with four engines damaged) [4].

Canada Geese have already caused one major aviation accident. For example, in September 1996 a US Air Force E-3A AWACS aircraft crashed after two engines were seriously damaged by a flock of Canada Geese at take-off., killing the crew of 24.

4. DETERMINATION OF IMPACT FORCE

In classical mechanics, impulse or impact refers to something that changes momentum of an object. The impulse of force acting for a given time interval is equal to the change in linear momentum produced over that interval. It is denoted as J and it is quantified through the product of a force, F, and the time, t, during which it acts. Impulse is a vector quantity since it is the result of integrating force, a vector quantity, over time. The SI unit of impulse is the Newton second (Ns) or, in base units, the kilogram meter per second (kg·m/s). Thus, for cases where the mass is constant, the impulse is defined as:

$$J = F\Delta t = mV_f - mV_i \qquad (1)$$

where:
F is the resultant force applied,
Δtt duration of impact,
m is the mass of the object,
v_2 is the final velocity of the object at the end of the time interval,
v_1 is the initial velocity of the object when the time interval begins.

Under the following assumptions equation (1) becomes equation (2):

- Head on collision
- Bird is riding with the aircraft after the collision
- Bird's velocity is negligible compared to that of the aircraft
- Total time taken to crush the bird (estimated impact time)
- Impulsive applied to the bird

$$F = \frac{mV_f}{\Delta t} \qquad \left[\frac{kgm}{s^2}\right] \qquad (2)$$

The above expression could be used for the calculation of the force generated by the collision between an aircraft. The estimated impact time, for all practical purposes, could be determined as a ratio of the length of the bird, (LB), and the speed of the aircraft, (AV), thus:

$$\Delta t = \frac{BL}{AV} \qquad [s] \qquad (3)$$

For example, the impact force of 101338 N (10.3 tonnes) will be generated in the collusion between an aircraft that flies 260 m/s and a bird whose length is 20 centimeters and weight 300 grams.

5. AIRBUS A320

The first Airbus A320, launched in March 1984, first flew on 22 February 1987, and was first delivered in 1988. The A320 family pioneered the use of digital fly-by-wire flight control systems, as well as side-stick controls, in commercial aircraft.

The Airbus A320 family are narrow-body (single-aisle) aircraft with a retractable tricycle landing gear and are powered by two wing pylon-mounted turbofan engines.

5.1 Airframe

The Airbus A320 is a low-wing cantilever monoplane with a conventional tail unit with a single vertical stabilizer and rudder. Wing swept back at 25 degrees, optimised for a maximum operating speed of 0.82. In addition, the aircraft has a cargo hold equipped with large doors to assist in expedient loading and unloading of goods.

The Airbus A320 is the first narrow body airliner to use a significant amount of structure made from composite material. Its tail assembly is made almost entirely of such material by the Spanish company CASA, which also build the elevators, main landing gear doors, and rear fuselage parts.

5.2 Flight Deck and Avionics

The Airbus A320 is a digital fly-by-wire aircraft: whose flight control surfaces are moved by electrical and hydraulic actuators, controlled by a digital computer. The computer interprets pilot commands via input from a side-stick, making adjustments on its own to keep the plane stable and on course, which is particularly useful after engine failure by allowing the pilots to concentrate on engine restart and landing planning.

The A320's flight deck is equipped with an Electronic Flight Instrument System (EFIS) with side-stick controllers. At the time of the aircraft's introduction, the behaviour of the fly-by-wire system (equipped with full flight envelope protection) was a new experience for many pilots. The A320 features an Electronic Centralised Aircraft Monitor (ECAM) that gives the flight crew information about all the systems of the aircraft. With the exception of the very earliest A320s, most can be upgraded to the latest avionics standards, keeping the aircraft advanced even after two decades in service.

5.3 Engines

The mechanical energy generated by the two engines is the primary source of routine electrical power and hydraulic pressure for the aircraft flight control systems The aircraft also has an auxiliary power unit (APU) which can provide backup electrical power for the aircraft, including its electrically powered hydraulic pumps; and a ram air turbine (RAT) a type of wind turbine that can be deployed into the airstream to provide backup hydraulic pressure and electrical power at certain speeds. Both the APU and the RAT were operating as the plane descended into the Hudson, although it was not clear whether the RAT had been deployed manually or automatically.

Three suppliers provide turbofan engines for the A320 series: CFM International with its CFM56, International Aero Engines, offering the V2500 and Pratt & Whitney whose PW6000 engines are only available for the A318 variant.

CFM International is a joint venture between GE Aviation, a division of General Electric of the United States and Snecma, a division of Safran of France. The joint venture was formed to build and support the CFM56 series of jet engines.

5.4 Incidents and Accidents of A320

In aviation industry negative functionability events are recognised as:

- An aviation incident is defined as an occurrence, other than an accident, associated with the operation of an aircraft that affects or could affect the safety of operations.
- An accident in which the damage to the aircraft is such that it must be written off, or in which the plane is destroyed is a hull loss accident.

6. BRANTA CANADENSIS

Branta Canadensis, commonly known as Canada Geese, are well known birds that reside within the United States, Canada and Northern Europe. However, biologists recognise 11 subspecies of Branta Canadensis. In the mid-Atlantic region of the USA, the Giant Canada goose is most common. The Canada goose has a greyish-brown body and wings, a white breast, black feet, bill, and neck, and a characteristic white patch on each cheek. Although body size varies somewhat among the subspecies, most individuals range between 1.5-9.5 kg. Giant Canada goose, males typically reach 4.5-78.0 kg as adults, whereas females usually are slightly smaller, reaching about 4-6.7 kg at maturity. Canada geese are relatively long-lived animals-it is not unusual for an individual bird to live up to 25 years.

Today, two distinct behavioural patterns in Canada geese are recognised, those that are truly migratory and those that are non-migratory (or resident). Migratory Canada geese spend the spring and summer on the breeding grounds in the northern parts of their range and then fly south during fall to their wintering range. In contrast, resident Canada geese spend much of the year in the same general area and fly only far enough to find food or open water (especially in winter when ice has covered their ponds).

The Atlantic Flyway population of migratory Canada geese has been in decline for over a decade, whereas the population of resident geese has seen near exponential growth. Because they never leave their familiar year-round habitats, and due to this dramatic increase in population size, resident geese are responsible for most conflicts with farmers and home and business owners.

The range of migratory Canada geese along the Atlantic coast extends from north-eastern and central Canada south to South Carolina. Their summer breeding range extends throughout the southern Canadian provinces from Ontario to the Maritimes, whereas their wintering range extends from as far north as western New York, through Delaware, Pennsylvania, and Maryland, south to Virginia, North Carolina, and South Carolina.

7. MIRCE MECHANICS ANALYSIS OF THE AIRCRAFT N106US

The aircraft that collided with Canada geese was an Airbus A320-214, registered as N106US. It was "born" at Airbus final assembly at Aéroport de Toulouse-Blagnac in France in June 1999. It was delivered to the US Airways on August 2, 1999, but it was registered to Wells Fargo Bank Northwest, NA, as owner/lessor with AIG listed as the lead insurer. It was one of 74 A320s in service in the US Airways fleet at that time.

Maintenance records, required by USA Federal Aviation Administration, FAA, showed that up to the collision the airframe had logged 16,299 cycles (flights) totalling 25,241.08 flight hours. Total time on the engines was 19,182 hours on the left, known as number 1, and 26,466 hours on the engine number 2.

The engine number 1, serial number (S/N) 779-828, was manufactured on September 12, 2000, and installed on the airplane on January 15, 2008. At the time of installation, it had accumulated 16,233 hours and 11,897 cycles since new (CSN). At the time of the accident, the left engine had accumulated 19,182 hours, 13,125 CSN, and 2,949 flight hours since its last maintenance inspection.

The right engine, S/N 779-776, was manufactured on February 16, 2001, and installed on the airplane on May 28, 2006. At the time of installation, the right engine had accumulated 17,916 hours and 6,755 CSN. At the time of the accident, the right engine had accumulated 26,466 hours, 10,340 CSN, and 8,550 flight hours since its last maintenance inspection.

The last A Check, a maintenance check performed every 550-flight hours, was passed on December 6, 2008, whereas the annual comprehensive inspection, known as C Check, was completed on April 19, 2008.

Flight Data Recorder (FDR) extracted from the aircraft was in good condition, and the NTSB verified all of 178 parameters of aircraft flight information for the entire flight were extracted normally.

The change in functionability states of the different parts of the aircraft caused by the bird-strike event and consequential ditching into the river is briefly presented here [6]. Thus:

- The left engine was found separated from the wing, while the right engine was found attached to the wing. The horizontal and vertical stabilizers and portions of the movable control surfaces remained attached to the aircraft. The nose and main landing gear remained attached to the aircraft and were found in the up-and-locked position.
- Both the forward and aft cargo doors were open when the aircraft was lifted from the river. The forward cargo door frames, rollers, latches, and drift pins were in good condition and without any signs of deformation. The forward cargo door interlock mechanism exhibited no signs of damage and functioned properly. The aft cargo door latches and rollers were in good condition, but the door frame structure was fractured at multiple locations. The aft cargo door handle was fractured into multiple pieces.
- The cabin of the aircraft was intact, and no crew or passenger seats were dislodged. The left, forward passenger door was found open, undamaged, and in the armed mode. The right, forward passenger door was found open and in the armed mode, and it could not be closed. The door was twisted on its hinge, and two tie rods had separated. The left aft passenger door was found open and in the armed position as its slide/raft was deployed during the recovery operations. The right aft passengers door was found closed and in the armed position.
- The fuselage and wings sustained damage during the bird-strike event, ditching, and recovery efforts. The upper portion of the radome exhibited dents, a crushed honeycomb core, skin fractures, and punctures consistent with damage sustained during the ditching and recovery efforts.

Full results of the analysis performed by the National Transportation and safety Board of USA are available in [6].

8. IMPACT OF NEGATIVE FUNCTIONABILITY EVENT ON ENGINES

Visual examinations revealed that all of the fractured surfaces on both engines were consistent with overload, and no signs of pre-existing damage or fatigue-type failures were found. Sixty ultraviolet light inspections of both engine cores revealed that foreign material consistent with bird feathers and tissue was inside the engine.

8.1 The Left Engine

The left engine was found near the initial impact location of the aircraft with the water, 8 days after the accident. Examinations revealed that the left engine had separated at the front and rear wing attachment fittings. The nacelle was fractured and deformed in several locations. No indication of engine uncontainment was found. The thrust reverser was found in the stowed position.

The left engine inlet lip was intact but exhibited crushing and had an 8- by 9-inch dent, consistent with soft-body impact, at the 4 o'clock position 56 of the lip. The outer nacelle skin aft of the inlet lip was fractured at the 3 to 9 o'clock position, and the lower portion of the skin was missing. The exhaust duct was present but crushed.

All fan blades, of the left engine, were present and intact but were bent aft about 1 to 3 inches in a predominantly skewed fan-plane pattern. All of the blade leading edge tips were curled in the direction opposite of rotation, and the curled-edge size ranged from very small to about 1/4 inch. The trailing edge of one fan blade was torn and notched with about 3/8 inch of material folded. The trailing edges of three fan blades were notched in a circular shape with about 1/4 to 3/8 inch of material folded in the direction opposite of rotation.

Foreign material consistent with bird feathers and tissue was found on the outer surface of the outer vane ring at the location of the fractured vanes. Further, five stage-1 HPC blades were found fractured, and the remaining blades were battered and bent. The stage-0 HPC variable guide vanes (VGV) were found disconnected from the VGV actuator.

The left engine combustor case was intact and appeared to be undamaged. When disassembled, examination of the combustor dome revealed crushing on the forward dome section between the 3 and 6:30 clock positions consistent with soft-body impact damage.

8.2 The Right Engine

The right engine was found still attached to the aircraft. Examinations revealed that the right engine nacelle was fractured and deformed in several locations. No indication of engine uncontainment was found. The thrust reverser was found in the stowed position.
The right engine inlet lip appeared to be undamaged. The acoustical panels in the inlet duct appeared to be undamaged except for a small section between the 11 and 12 o'clock positions.

The right engine spinner was intact and undamaged. The front of the spinner cone exhibited a brown stain about 4 inches long starting about 2 inches from the tip. All of the right engine fan blades were present and intact but were bent aft about 1/2 inch. Five of the right engine fan blades exhibited a large-radius curvature 59 dents at the midspan location. A portion of a feather was found stuck between two adjacent fan blades at the midspan damper.

The right engine combustor case was intact and appeared to be undamaged. When disassembled, examination of the combustor dome revealed crushing on the forward dome section consistent with soft-body impact. About 1 cup of charred remains was found in the combustor area.

9. THE "DITCH SWITCH"

The Airbus A320 has a "ditching" button that closes valves and openings underneath the aircraft, including the outflow valve, the air inlet for the emergency RAT, the avionics inlet, the extract valve, and the flow control valve. It is meant to slow flooding in a water landing.

However, the flight crew did not activate the "ditch switch" during the incident. Captain Sullenberger later noted that it probably would not have been effective anyway, since the force of the water impact tore holes in the plane's fuselage much larger than the openings sealed by the switch [6].

10. MIRCE MECHANICS ANALYSIS OF BIOLOGICAL MATERIAL

As Mirce Mechanics studies the life of maintainable system in its entirety no analysis could be completed without addressing the natural environment with which they continuously interact.

Consequently, Mirce Mechanics analysis could not have been completed without analysing the physical properties and characteristics of the birds as a second element of the bird strike phenomena.

Investigators from the National Transportation and Safety Board of USA collected ten samples of biological material from the right engine fan, the radome, the No.3 flap track on the left wing, and various locations on the fuselage. Two additional samples were collected from the shroud from the No.3 flap track on the left wing after it was removed from the aircraft. In addition, a United Stated Department of Agriculture, USDA representative and General Electric (GE) personnel collected six samples from the exterior of the left engine before its disassembly at the GE facility. At the end of the disassembling process of the left engine, an additional 23 samples of biological material were found, including feathers, blood, muscle, and bone. A similar operation on the right engine disclosed another 14 samples of the same type of biological material. [6]

Samples collected from both engines were analysed by the Feather Identification Laboratory of the Smithsonian Institution, National Museum of Natural History, Division of Birds, in Washington, DC. The DNA analysis has shown that 39 of the samples matched 99 % or more, of the Barcode of Life Database for Canada goose. All 53 samples, where 50 of them were from the engines, contained feathers or feather fragments consistent with Canada geese. Analysis of the DNA shown that 16 of the 18 samples found in the left engine wing were male and female, while only male remains were found in the right engine, and only female remains were found on the No.3 flap track on the left wing.

10.1 Residential or Migrating Canadian Geese

Determining whether the geese involved in this functionability event were resident or migratory is essential to the development of management techniques that could reduce the risk of future collisions. Currently, the US civil aviation industry is not required to report bird strikes, yet information on frequency, timing, and species involved, as well as the geographic origin of the birds, is critical to reducing the number of bird strikes. Integrating this information with bird migration patterns, bird-detecting radar, and bird dispersal programs at airports can minimize the risk of such collisions in the future.

However, applied DNA sequences techniques were able to identify the species, but they could not determine if these birds were local Canada Geese from the New York area or migratory geese spending the winter in the New York region. Under the leadership of Dr Marra, the team from the Smithsonian Migratory Bird Center, National Zoological Park, Washington, DC, analysed the stable isotopes in the feathers. Isotopes are naturally occurring variants of elements, and in the case of hydrogen there is documented geographic variation associated with latitude. Hence, the team studied the isotopes in goose feathers comparing those from the plane crash with migratory and non-migratory birds to answer the question posed. [7]

The analyses were conducted and isotopic data resulted in the determination of a non-local origin for the Canada Geese that struck the plane. Even further, stable isotope analyses of feathers recovered from the engine specifically concluded that the geese had spent their summer farther north than Labrador. These findings were significant on several fronts. First and foremost were the implications from a wildlife management perspective. Had the geese been determined to be from a local New York population, it is highly likely that the local population would have been culled or exterminated. Determining that these particular geese were migratory requires a completely different management plan to reduce, or prevent, such bird strikes in the future. The use of deuterium isotopes to effectively "source" the geese was a novel application of isotopic research.

11. CONCLUSION

The main objective of the paper was to present Mirce Mechanics type of analysis of the negative functionability event that occurred on 15th January 2009 during the scheduled flight of the USAir Airbus A320. Hence, this paper addresses the collision between birds and flying objects, commonly know as a bird strike. This is a typical example of the overstress failure mechanisms where a huge amount of kinetic energy is generated by the collision of both flying objects. Consequently, the paper analysed mechanisms of the motion of the USAir A320 through functionability states caused by the kinetic energy generated by the collision with a flock of Canadian Geese during the flight 1549. The consequences of the occurrence of the negative functionability event in the fuselage and engines are analysed and presented here, together with the brief analysis of biological material collected from the damaged aircraft, after it was lifted to the surface of the Hudson River.

For the completion of the Mirce Mechanics analysis it is necessary to mention that Aircraft N106US has never entered into positive functionability state again, as a flying machine. However, after changing the functionality and becoming an exhibit at the Carolinas Aviation Museum in Charlotte, North Carolina., it fulfils its functionability performance by staying in positive functionability state during the working hours.

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