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2013-04

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Journal of Mechanics Engineering and Automation, Libertyville, v. 3, p. 238-246, 2013
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The Influence of Demoiselle Aircraft on Light and General Aviation Design

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Received: January 3, 2013 / Accepted: January 30, 2013 / Published: April 25, 2013.

Abstract: In 1907, aviation pioneer Santos-Dumont had the idea of building a very light airplane. He designed and built the SD19, the Demoiselle, an aircraft with a 6 meter wing span and a 24 HP engine of his own design. The Demoiselle was very successful in flying and, became very popular and its development continued as SD20, SD21 and SD22 (his last airplane). The influence of the Demoiselle on design principles of light aircraft and general aviation were studied in this work, using statistical entropy. The designs number 20 and 22 may be considered dominant and influenced the design principles of light aircraft and general aviation.

Key words: Demoiselle, Santos Dumont, general aviation, aircraft design, statistical entropy.

1. Introduction

Scaling of design in the industry needs to be taken into account the rate of diffusion of the relationships between the characteristics of a product. On the other hand, the codification of design principles associated with the emergence of a dominant design implies the divergence of a particular principle of design that had been developed in the past. This is only a point in the evolution curve and future direction of this evolution can generally be predicted by the knowledge of its past. In other words, we must often go beyond the past to have a clear idea of the future. It is important that the engineer understands the historical development of their specialty. Information theory was first mentioned in an article titled "The Mathematical Theory of Communication". The main purpose of this study was to address the problem of information transmission through a noisy channel.

The statistical entropy is based in a probability distribution and presents satisfactory results for the evolutive phenomena for any population of heterogenic members [1]. Systems such as biological evolution, economic growth, image reconstruction and technological evolution in specific automobile and aerospace industries can be studied using the statistical entropy.

Utterback and Abernathy [2] have proposed the concept of life cycle to describe the technological evolution of the design a product development in 1975. If a certain technology has been established for a long period of time without presenting, major innovations can be concluded that the entropy or the uncertainty of the period is very low and the competitors, if any, borrowed innovations promoted in the past by this technology. At the beginning of the life cycle of a product, there are a variety of new products are being developed concurrently. Competition between designs is eventually resolved with the emergence of a design that is considered dominant. Later all the innovation will focus on process improvements and product increments with reference to that dominant design.

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The concept of the trajectory of a product can be evaluated with a dynamic comparison of a dominant design. Nelson and Winter [3] emphasized that these trajectories relate not only periods during which the basic principles remain unchanged technological, but also ordered phases (scaling) designs. One major example of a series of models ordered in civil aviation has been representing the trajectory of aircraft with piston engines and propeller passenger transport, designed and built by U.S. Douglas Company. Features such as engine power, wing span, fuselage length led to improvements in aircraft speed by a factor of two, and maximum takeoff weight and range by a factor of five since the introduction of the Douglas DC-3 aircraft in December 1935 until the appearance of the aircraft Douglas DC-7 in 1956 [4].

The aviation pioneer Alberto Santos Dumont designed and flew more than 22 prototypes from light than air spherical balloons, airships and heavier than air biplanes and monoplanes. After his successful first complete flight with the 14-bis airplane in October 1906 in Paris Santos Dumont sweep from the canard/pusher configuration to the tractor tail aft one. In the subsequent models the SD-15 and SD-17 where tractors and big biplanes and they not succeed to fly due to structural and aerodynamic issues. However, the concept of tractor propeller and tail aft was established and Santos Dumont designed and flew in November 1907 his design number 19 latter called Demoiselle. He finally completed the configuration proposed by Cayley still in the early eighteenth century: a monoplane with a cruciform tail on the end of a long tubular fuselage [5]. The engine was installed in a cut on the leading edge of the wings that had a generous dihedral to ensure lateral stability. The pilot sat beneath the wings in a tubular structure where there were three wheels. The landing gear allowed a wide clearance for the propeller and incidence adequate for takeoff. His first flight Demoiselle was approved by the judges of the Aero Club of France as can be seen in Fig. 1. Small, fast, stable and secure at all like a modern ultra-light,



Fig. 1 First flight of the SD 19 Demoiselle in November 1907, Paris.

SD 19 had a good performance, but it was a very fragile device. From it, the SD 21 Demoiselle designed in 1909 was developed, and copied across Europe and USA. The SD 19 must be regarded as the first modern airplane. The Demoiselle should be considered as the precursor of the modern airplane as it was the first airplane that fully satisfies the criteria for physical and conceptual precursors: performs the same basic function, unassisted take-off, maneuvering and landing. It is a link in an unbroken chain that leads to the modern airplane through incremental development. Fig. 2 shows the model SD 21 which drawings were sent for free to Popular Mechanics magazine in 1910. Santos Dumont gave permission for the Clément Bayard and Dutheil & Chambers Companies to build and sell the Demoiselle for 7.500 francs and it was used as a trainer by the Finish and Austrian aerial corps from 1910 to 1913.

The influence of the Demoiselle on design principles of light aircraft and general aviation were studied in this work, using statistical entropy. The methodology used for this work is that described by Frenken and Leydersdorff in 1999 [4]. The designs are organized by the first flight, or first operational flight as reference date. The main characteristics of the aircraft are stored into a database.

The parameters chosen for analysis were: wing loading, power loading, empty weight ratio and total weight, structural efficiency, structural efficiency ratio and wing loading, global configuration, construction materials and lift coefficient. This paper assesses the critical and transitional rates of diffusion and convergence of the aircraft designs. The combination of these indices in the timeline sets the schedule of technological change.

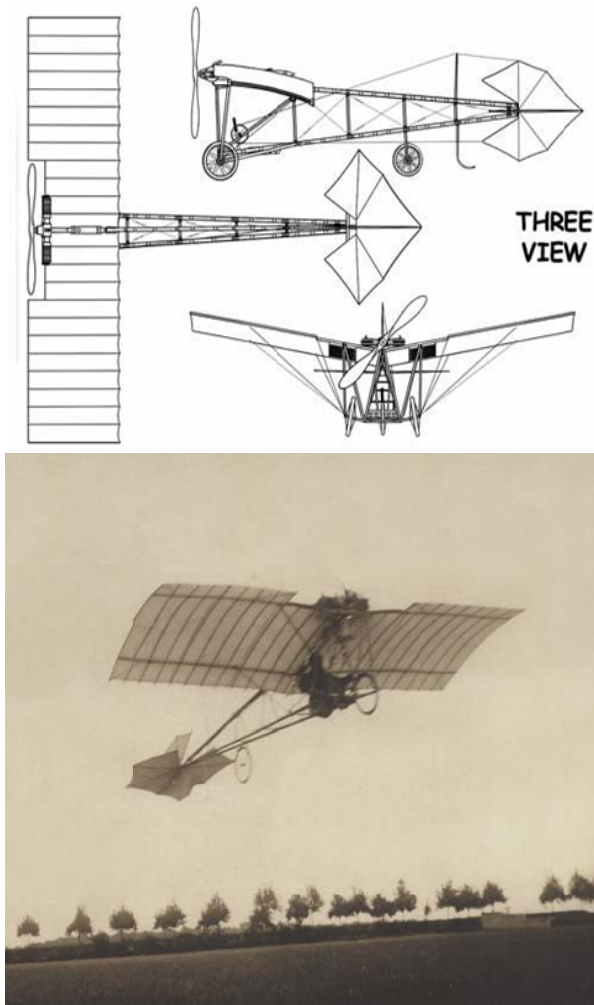


Fig. 2 Santos Dumont design number 21 Demoiselle.

The paper is organized as follows: Section 2 discusses the objective; section 3 introduces the methodology used; section 4 describes the Demoiselle family; section 5 introduces the data base; section 6 presents results and discussions; section 7 gives conclusions.

2. Objective

Scaling design-level industry needs to take into account the rate of diffusion of the relationship between product characteristics. On the other hand, the coding of the design principles associated with the emergence of a dominant design involves a principle of divergence of particular design that was developed in the past.

3. Methodology

3.1 The Measurement of the Dynamic Distance Based on the Information Theory

According to Frenken and Leydersdorff [4], the designs represent the interface between supply and demand and since it is expressed as a function of the commitments among characteristics, the orderly arrangement is demonstrated when these commitments remain solved along the time.

The product interest characteristics are selected; it is evaluated a relationship among them and with characteristics of other products. If there is no evident variation in relationships, the design is not innovative.

Be $A_1, A_2, A_3 \dots A_n$ the airplanes in study and $C1_{A1}, C2_{A1}, C3_{A1} \dots Cn_{A1}$ the characteristics of the airplane A_j . The relationship among the characteristics A_j may be done as follows:

$$R1_{A1} = \frac{C1_{A1}}{C2_{A1}}, \frac{C1_{A1}}{C3_{A1}} \dots \frac{C1_{A1}}{Cn_{A1}} \quad (1)$$

$$R2_{A1} = \frac{C2_{A1}}{C1_{A1}}, \frac{C2_{A1}}{C3_{A1}} \dots \frac{C2_{A1}}{Cn_{A1}} \quad (2)$$

$$R3_{A1} = \frac{C3_{A1}}{C1_{A1}}, \frac{C3_{A1}}{C2_{A1}} \dots \frac{C3_{A1}}{Cn_{A1}} \quad (3)$$

$$Rn_{A1} = \frac{Cn_{A1}}{C1_{A1}}, \frac{Cn_{A1}}{C2_{A1}} \dots \frac{Cn_{A1}}{Cn-1_{A1}} \quad (4)$$

The same procedure is done for $A_1, A_2, A_3, \dots A_n$ and the relationship group may be considered as a likelihood distribution by dividing each relationship by the sum of all of them obtaining $DP_{A1}, DP_{A2}, DP_{A3}, \dots DP_{An}$.

Thus there is a probabilistic representation of each airplane design under study. Based on information theory, it is possible to know the changes between subsequent designs, with the introduction of a new model in the market, calculating the distance between the representations in terms of probability distribution using the formula [6]:

$$I(q/p) = \sum_{i=1}^n q1^* \text{LOG}_2 (q1/p1) \quad (5)$$

The result of the information content of the posterior distribution ($q1 \dots qn$) due to the previous distribution

($p_1 \dots p_n$) may be considered as a theoretical distance based on the designs information in terms of relationships. Therefore, IF there are no changes in the commitments (trade-off), the likelihood distribution stays the same and in comparison with previous designs, it is verified that the design is an adapted version of them.

In that case, every q_1 is equal to the correspondent p_1 , therefore, I disappears because $\text{LOG}(1) = 0$, otherwise, being I a positive number, indicates entropy occurrence [6-7]. The I value is used as a measure of the relationship grade between two designs. Considering the analysis of two airplanes, the lower the I value, the more similar are the ratios between the airplanes characteristics, and in this case, the later design may be considered as adapted version of the previous.

3.2 The Critical Transition Measurement

The advantage of the algorithm is becomes clear when three designs examples are compared in sequential series: A-B-C.

Considering a Euclidian space, the distance between A and C is smaller than the sum of the distance between A and B and between B and C (Pythagorean Theorem).

In contrast, the theoretical distance of the information of designs A and C indicated by $I(C/A)$ is not necessarily smaller than the sum of the distance between designs A and B, $I(B/A)$ and B and C, $I(C/B)$. In this case,

$$I(B/A) + I(C/B) < I(C/A) \quad (6)$$

The theoretical distance formula is equivalent to

$$I(B/A) + I(C/B) - I(C/A) \quad (7)$$

And, if the inequality is confirmed, the transition from design A to design C, by design B may be considered as a Critical Transition.

3.3 Diffusion and Convergence

Diffusion and convergence are different phenomena. The diffusion of a particular design principle does not imply convergence, since the design can be set to different and potentially conflicting directions. For example, some companies may classify a dominant

design with reference to the maximum takeoff weight, and others with respect to the range or speed. If the diffusion of a design principle is observed over time, convergence can be achieved through its retrospective. The diffusion of design may be measured as the temporal distance " T " in accordance with Eq. (5) for all members of the population technology as a future event later in time. Diffusion here refers to the subsequent classification of a particular product design and not its diffusion in terms of sales. A low value of I indicates a high degree of design diffusion. While a high value of I indicates a low degree of diffusion. Recalling that $I(q/p)$ is a reverse indicator.

The degree of convergence is defined as the temporal distance between all the products of a population with last time the product was utilized in the population. That is, a design introduced in time t_n is compared to all designs introduced during the period t_1 to t_{n-1} . The mean value I indicates the degree of convergence where a low value of I indicates a high degree of convergence and a high value of I indicates a low degree of convergence.

The problem formulation is similar to diffusion except that the cumulative convergence is counted from the date of " T " aircraft design study to date of the first design under study, retroactively.

Although the cyclic curves resulting from graphs of diffusion and convergence are similar, the time delay in the minimum and maximum values suggests that designs have their individual values of diffusion very different from the values of convergence. In other words, these aircraft which had a strong impact in the industry are not necessarily those that converged to a given design, and vice versa [8]. An aircraft which a specific design converged, not necessarily will promote a diffusion of this design throughout the industry [9].

Four types of designs can be distinguished in terms of their values (low and high) diffusion and convergence, following Fig. 3 we have

- Designs located in the southwest quadrant with low I values of diffusion and low value of convergence are classified as "Dominant";

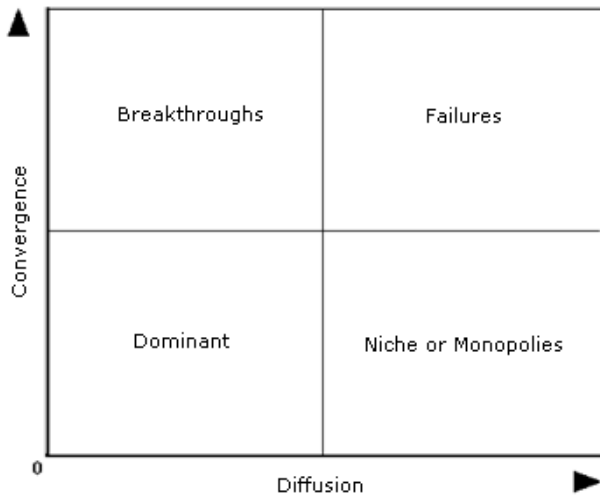


Fig. 3 Diffusion and convergence frame.

- Designs located in the southeast quadrant with high I values of diffusion and low value of convergence are classified as “Niche or Monopolies”;
- Designs located in the northeast quadrant with high value and high I values convergence are classified as “Failures”;
- Designs located in the northwest quadrant with low value and high I values convergence are classified as “Breakthroughs”.

4. The Demoiselle Family

The Brazilian Alberto Santos-Dumont started the development of the project No 19 in order to win the Grand Prix d’Aviation established in 1907 by Ernest Archdeacon and Deutsch de la Meurthe. After the success flights of the 14-Bis in October 1906, Santos Dumont realized that the pusher/canard configuration had some lateral-directional stability problems which could be solved with the tail aft configuration. He tried to fly the SD 15 (Fig. 4) in March 1907, which was a tractor biplane without success due to its undercarriage wrong position [10].

The SD 17 (Fig. 5) was an evolution of the 15 with a conventional undercarriage; although he never tested this aircraft it had a promising configuration.

The SD 19 aircraft was the highlight at the Grand Prix and distinguished from the others by the simplicity and lightness of construction. The rear fuselage

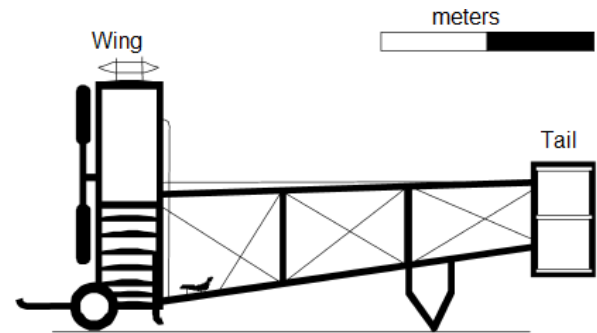


Fig. 4 Santos Dumont design #15 the undercarriage in wrong position did not allow rotation for take-off [10].

consisted of a single bamboo pole, the empennage fully mobile, high wing covered in silk with a wingspan of only 5 meters, weighed 56 kg empty and the pilot weight was 114 kg. SD19 was also the first project in the series to be called Demoiselle.

In 1908, Santos Dumont refined the Demoiselle, swapped the single bamboo pole fuselage by a triangular framework structure made by metal and bamboo, the wing span was increased to 5.55 m. The inventor started to call him SD 20, which makes its first flight in SaintCyr in March of 1909.

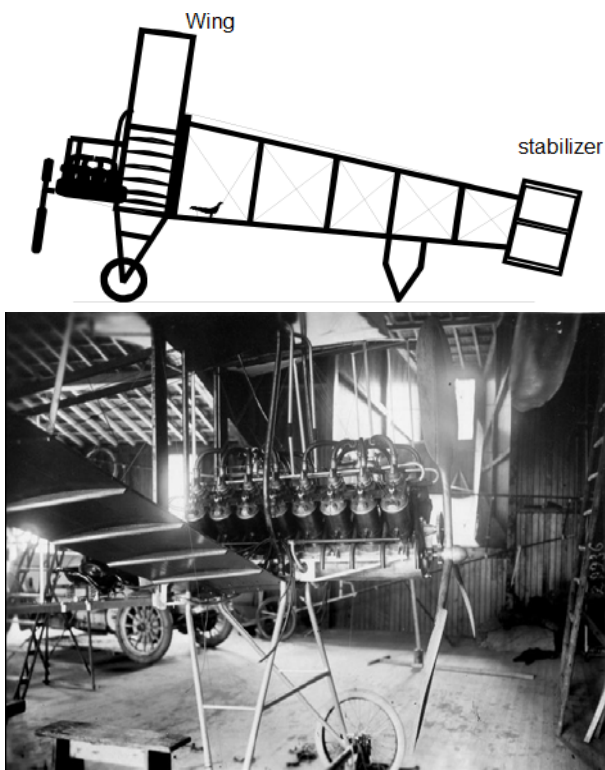


Fig. 5 Santos Dumont design #17, a more powerful engine and the undercarriage in the right position [10].

On September 5 the same year, he makes a test flight with the new 34hp Darracq engine and new wooden propeller. The model was called SD21.

On September 13, the SD 21 covers nine kilometers from SaintCyr and Buc and in September 16, he took off with a ballast of 20 kg and dropping it in flight to test the stability of the aircraft. Santos Dumont used this aircraft for their flights and gave permission, without any participation in the profit, for the factories Clément Bayard and Dutheil & Chambers to build and sell it. The only requirement was in the price which should not exceed 7.500francs. Just over 100 examples of the SD 21 were built and the design drawings were published for free in North American Popular Mechanics Magazine. Finally the show ends with the model SD 22, the latest version of Demoiselle in which Santos Dumont made his last flight in 1912. The model No 22 was very similar to model SD21, differing only in the installation of Clement Bayard motor of 40 hp of power. Table 1 present the technical specifications of the models SD 19, 20, 21 and 22 used in this work [11].

5. The Database

The Brazilian Santos Dumont and the Wright brothers stand out as pioneers of aviation and the dispute over who was the inventor of the aircraft still occurs today. Many have tried flying, some gave-up, and some failed, others have not had the chance to try it again and others remained anonymous.

When making the database for this study, it was surveyed several designs done prior to the Santos Dumont and the Wright brothers. However, very little or no information about the technical characteristics of those aircraft were obtained. Precursors such as John Strinfellow, Jean-Marie Le Bris, Hiram Maxim, Philips and New Zealander Richard Pearse, etc. presented a lack of technical information about their designs. It is claimed that Pearse flew and landed an interesting machine heavier than air in March 31, 1903, about nine months before the Wright brothers flew their aircraft and whose replica built by Ivan Mudrovich awaiting authorization to be tested this year in New Zealand.

The record in the database begins in 1907 with the aircraft followed by the SD19 Demoiselle, Farman III, Flyer III, the SDs 20, 21 and 22, etc. After the year 1907 and until today, the aircraft category for the proposed study and its technical characteristics are readily available in many bibliographic references.

For this work, the aircraft designed during the First and Second World Wars were excluded.

5.1 Variables in Study

The selected design parameters for case study are as follows:

- Wing Loading: (W_o/S_w)

$$W_o = TotalTake - offweight$$

$$S_w = Wing\ area$$

- Weight-Power Ratio: (W_o/Hp)

$$Hp = Motor\ power$$

- Structural Efficiency:

$$EE_{est} = \frac{W_o - W_{empty} - W_{motor}}{W_{empty}}$$

$$W_{empty} = Airplane\ empty\ weight$$

$$W_{motor} = Airplane\ motor\ weight$$

Table 1 Demoiselle family technical specifications.

	D_19	D_20	D_21	D_22
Year	1907	1908	1909	1909
We (kgf)	56	110	110	110
Wo (kgf)	120	194	194	194
Bw (m)	5.0	5.5	5.5	5.5
Sw (m ²)	10.20	10.20	10.20	10.20
AR	2.45	2.96	2.96	2.96
Seats	1.0	1.0	1.0	1.0
Engine	Dutheil Chambers	Antoinette	Dutheil Chambers	Clemént Bayard
HP	18	24	30	40
Weng (kg)	27	36	45	60
V _{max} (km/h)	75	96.6	96.6	96.6
Lmax (m)	8.0	6.2	6.2	6.2
Land_gear	TD	TD	TD	TD
W/S (kgf/m ²)	2.411	3.890	3.890	3.890
W/HP (kgf/HP)	14.708	17.795	14.236	10.677
We/Wo	0.465	0.567	0.567	0.567
Effestrut	0.667	0.438	0.356	0.219
Effestrut/W/S	0.277	0.112	0.091	0.056
Effestrut/W/HP	0.045	0.025	0.025	0.021
CL_Vmax	0.285	0.277	0.277	0.277

where

TD = Tail Drag
 We = Empty Weight
 Wo = Total Weight
 Bw = Span Wing
 Sw = Wing Area

AR = Aspect Ratio
 Weng = Engine Weight
 Vmax = Maximum Speed
 Lmax = Maximum Length
 W/S = Wing Load
 Effestrut = Structural Efficiency

- Structural Efficiency and Wing Loading:

$$EE_{est} / (W_o / S_w)$$
- Structural Efficiency and Weight-Power Ratio:

$$EE_{est} / (W_o / Hp)$$
- Configuration—The adopted values are
 - (1) One for monoplane
 - (2) Two for biplane
 - (3) Three for biplane/canard

The wing configuration parameter is related to the relative position and the number of wings, monoplane or biplane, and the relative position to the empennage (conventional or canard).

- Fuselage Length by Total Weight:

$$L_{fus} / W_o$$
- Lift Coefficient at Maximum Speed:

$$CL_{Vmax} = \frac{W_o}{qS_w}$$

$$q = \text{Dynamic Pressure} = \frac{\rho V_{max}^2}{2}$$

5.2 Considerations

Regarding of data not provided or unavailable, the following considerations were made:

(a) The empty weight of the aircraft Flyer IV, owned by the Wright brothers was calculated by subtracting the weight of Orville Wright as pilot, the total weight of the aircraft.

(b) The engine weight, that is not found, was calculated as follows:

- For engines built between 1907 and 1928, the value of the weight of the motor is obtained as the value of its horsepower multiplied by 2 kg;
- The maximum speed for pioneer aircrafts in the period between 1907 and 1909 was considered as the measured speed at the time of flight.

(c) About the selection of aircraft for study, limits have been set up for wing loading of 70 kgf/m² and

minimum power load of 4 kgf/Hp.

6. Results

6.1 Diffusion

From Fig. 6, it is possible to see that the Demoiselle family has the smallest I values in the dawn of aviation, meaning higher diffusion.

6.2 Convergence

From Fig. 7, it can be seen that the Demoiselle Airplanes Family has higher convergence (low values) compared to the airplanes designed and built in the early's of aviation. This result means that the Demoiselle Family is not based in principles of previous successful airplanes.

6.3 Diffusion and Convergence

By analyzing Fig. 8, it is possible to show that the Demoiselle Family were dominant and conducted the design principles of the category in study. In fact many designs adopted the monoplane, tail aft and conventional landing gear even for the pre-WWI aircraft such as the Bleriot, Morane-Saulnier family and the Fokker Eindeckers family. With the development of more powerful engines the necessity of more strongly wing structure and lift generation led the designers to adopt the biplane or ever three-plane configuration. Although, with the development of more thick aerodynamic profile and light metals the monoplane configuration both semi-cantilever and cantilever wing structure, returns as the best configuration for all class of aircrafts.

7. Conclusions

Among the Demoiselle aircraft family, the designs number 20 and 22 may be considered dominant and influenced the design principles of light aircraft and general aviation, it is a link in an unbroken chain that leads to the modern airplane through incremental development. As Santos Dumont made public all his achievements including the drawings of the SD-20, the

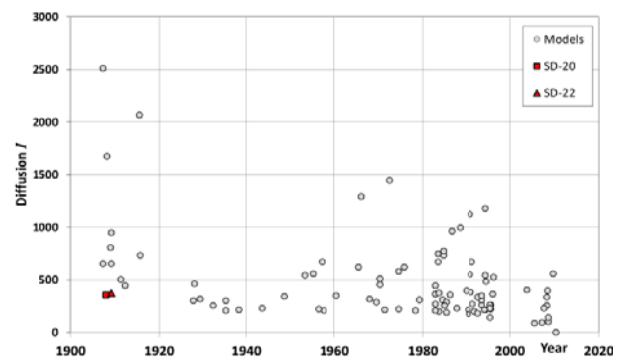


Fig. 6 Diffusion results.

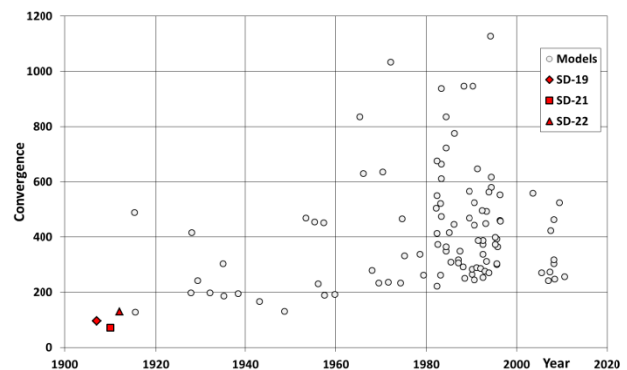


Fig. 7 Convergence results.

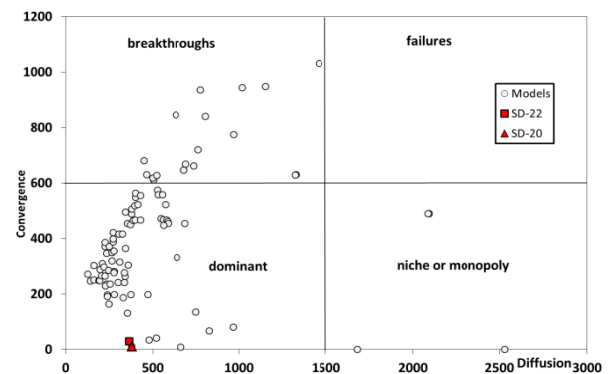


Fig. 8 Convergence and diffusion results.

Demoiselle model could be upgraded through the years by the owner with new features. These upgrades made the aircraft more easy to fly and safer and a legion of new pilots, home builders and aviation enthusiastic could enjoy the magic of flying. One of the most popular aviators at that time was Roland Garros. Garros had just the enough 7.500francs to buy a Clément Bayard Demoiselle in 1909 when he visits “La Exposition de la Locomotion Aériene”. Garros flew with his Demoiselle through Europe and in the

USA. One important event was an aerial race in 1911 from Paris to Madrid where Garros completed the 400 kilometers in 4 hours and 52 min. Garros had the honor to pilot the SD-22 Santos Dumont personal Demoiselle in 1912. Santos Dumont realize that he was the only one who could fly his little, beautiful and elegant Demoiselle.

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