AIAA 2001-0311
Flying Wings / Flying Fuselages

Richard M. Wood and Steven X. S. Bauer
NASA Langley Research Center
Hampton, Virginia

39th AIAA Aerospace Sciences
Meeting & Exhibit
8-11 January 2001 / Reno , NV

Flying Wings / Flying Fuselages

Richard M. Wood and Steven X. S. Bauer[†]

ABSTRACT

The present paper has documented the historical relationships between various classes of all lifting vehicles, which includes the flying wing, all wing, tailless, lifting body, and lifting fuselage. The diversity in vehicle focus was to ensure that all vehicle types that may have contributed to or been influenced by the development of the classical flying wing concept was investigated.

The paper has provided context and perspective for present and future aircraft design studies that may employ the all lifting vehicle concept. The paper also demonstrated the benefit of developing an understanding of the past in order to obtain the required knowledge to create future concepts with significantly improved aerodynamic performance.

INTRODUCTION

Even after more than a century of research and development the flying wing is still viewed as a unique and unconventional aircraft concept[1-47]. This reality is even more surprising when you consider the significant aerodynamic and structural benefits afforded flying wing designs, compared to conventional designs. Historical reviews[5,8,10,15,47] on this topic appear to point to a variety of reasons for the slow acceptance of flying wing type vehicles. From a technical point of view, the dominant issue has been stability and control, which to this day continues to plague this class of vehicle. As a result, flying wing aircraft continue to be limited to missions comprised of only low lift (cruise) conditions. In addition to the technical issues, there were cultural issues faced by this class of aircraft that consisted of negative public perceptions and politics. In the first half of the 20th century, which was the most prolific period of flying wing development, these two issues severely restricted technical discussions and as a result the opportunity to mature this concept was lost. The present cultural environment is slightly improved but the public perception and politics continue to haunt this concept today.

A review of the most recent aircraft design studies shows a significant number of flying wing concepts are under consideration, especially for military applications. It is clear that the realization of the flying wing concept is benefiting from recent technological advances in aerodynamics, flow control, flight control systems, materials, structures, and propulsions systems. It also appears that the cultural barriers of the past are also deteriorating allowing for the rich body of flying wing research to be shared and studied and thus, contribute to future vehicle development activities.

However, a review of the ongoing research indicates that we continue to re-create the past instead of learning from the past to create the future[48-53]. These sentiments are clearly stated through the following quotes from A. R. Weyl, 1944. [38-42,54]

"...Flying Wing, in which at the present period more interest than ever is being displayed."

"...it seems a fact that experience collected in the past with tailless aeroplanes is either unknown or forgotten or, at the least ill-judged..."

"...it is by no means sufficient that a crazy design flies; it must fly far better than everything else in order to raise attention among those closed circles..."

The relevance of these three statements after nearly six decades its quite remarkable. They point to the need for a thorough understanding of the design trends, historical contributions, and technical relationships for flying wing vehicles as well as other closely related vehicle types before significant work is performed. With this understanding will come new

† Senior Research Aerodynamicist, Configuration Aerodynamics Branch NASA Langley Research Center, Associate Fellow AIAA

design knowledge and thus, new opportunities to create new concepts that approach the optimum performance boundaries of powered flight. Failure to develop this understanding will ensure that we will once again re-create past accomplishments.

In support of this issue the present paper is focused on documenting the historical relationships between various classes of all lifting vehicles that includes the flying wing. The diversity in vehicle focus is to ensure that all vehicle types that may have contributed to or been influenced by the development of the flying wing concept are investigated. By investigating these relationships, it is expected that today's aircraft designers will have an improved understanding of the brilliant aircraft designs of the past.

The following definition of the All-Lifting-Vehicle (ALV) is offered:

A vehicle that has all horizontal orientated elements (i.e., wing, fuselage, tail, etc..) are continuous and aerodynamically shaped to contribute proportionally equivalent amounts of lift throughout the flight envelope.

This broad definition allows for the inclusion of all existing definitions for flying wing, all-wing, tailless, and lifting body. Note, the above definition does not allow for a vehicle that has a fuselage that does not provide appropriate lift, a tail/canard that only functions as a trim/control surface, or a nacelle that only houses the propulsion system. The various names that make up the ALV category are as diverse as the concepts themselves and vary from flying wing to flying fuselage. Definitions of the six specific concepts to be investigated are listed below to assist the reader.

Flying Wing [1-15,47,55-68]

A tailless airplane accommodating all of its parts within the outline of a single airfoil.

All-Wing

Aircraft consisting of nothing but wing. (Northrop's definition)

Tailless

An aircraft consisting of a single wing, without conventional fuselage or tail.

Flying Fuselage [10,69-116]

An aircraft consisting of an aerodynamically shaped fuselage that generates a majority of the total aircraft lift.

Lifting Fuselage

A thick aerodynamically shaped body with section lift characteristics equivalent to that of a wing.

Lifting Body

Aircraft that chiefly or solely generate lift by their bodies.

The discussion presented within the paper will use the Flying Wing (FW) and Flying Fuselage (FF) terms as the primary ALV descriptors with All-Wing and Tailless being sub-elements of FW and Lifting Fuselage and Lifting Body as sub-elements of FF.

A goal of this paper is to provide context and perspective for present and expected future aircraft design studies that may employ the ALV concept. It is also hoped that this paper will demonstrate the benefit of developing an understanding of the past in order to obtain the required knowledge to create future concepts with significantly improved aerodynamic performance.

The discussion that follows will first review the ALV historical development in an effort to focus the reader to the relationship between the various ALV types. The paper will then provide a more detailed discussion of the history of the FW concept. The final sections of the paper will focus on the historical development of ALV within the United States.

ALV HISTORY

ALV have been under continued development for over a century with the majority of the early work (pre 1950) centered in Europe and the post 1950 work being performed within the United States. This transfer in ALV leadership to the United States coincides with the transfer in the world economic and military leadership to the United States. This technical dominance by one country (United States) resulted in an increased conservatism in aircraft design during the middle decades of the 20th century. Most of these aircraft, designed since the 1950s, may be characterized as typical vehicles with wings to produce lift, fuselages to carry cargo/payload, tails/canards for control, and nacelles to house propulsion systems. Another change that drastically influenced aircraft design within the United States, in the post 1950 era, was the growing interest, effort, and resources expended toward space exploration. These efforts led to the development of lifting body aircraft for atmospheric reentry. However, recently there has been a new beginning in ALV design as evident by the Blended Wing Body (BWB) [49-53], X43, and Pathfinder.

An initial assessment of the history of ALV identifies three primary categories as noted in figure 1. These categories are flying wing, lifting fuselage, and lifting body. The chart of figure 1 shows that the flying wing category is the most populous with well over 125 aircraft whereas both the lifting fuselage and lifting body categories number well under 25 aircraft. The majority of both the flying wing and lifting fuselage aircraft were developed prior to 1950 whereas the lifting body work is all post 1950. A more detailed listing of all of these aircraft is presented in table 1.

A graph of the development time line for the flying wing, lifting fuselage, and lifting body ALV concepts is presented in figure 2. Noted on the figure, to the right of each ALV type time line, are the countries that have made significant contributions. It is interesting to note that the flying wing concept has been under continual development since the late 1800s. The chart also shows that the lifting body concept has had continued development since its inception in the late 1950s. However, the lifting fuselage concept has had a finite life span from the 1920s to 1950. The observed start and stops of the various all lifting vehicle concepts raises several questions concerning their influence on one another.

In order to address these questions, it is important that a shared understanding of what constitutes a flying wing, lifting fuselage, and lifting body is developed. While both the flying wing and lifting body concepts are well known by the community the same can not be said for the lifting fuselage concept. As a result, it is appropriate at this point to provide a brief discussion of each of the three concepts. For clarity, photographs of the three concepts are shown in figure 3.

The pure flying wing is best represented by the Northrop Grumman B-2[55,56] as shown in figure 3. However, for the present discussion, we have relaxed the definition and will include aircraft that have been termed both all-wing and tailless, as long as the subject aircraft does not have a significant fuselage extending forward or aft of the wing planform.

The lifting body concept is clearly represented by the NASA/Northrop M2-F2 as depicted in figure 3. Lifting body concepts are thick aerodynamic shapes that typically have vertical surfaces for stability and control. Nearly all lifting body development has been performed in the United States and was initiated within NASA in the 1950s.

The final concept is the lifting fuselage, see figure 3. The concept depicted is the Burnelli, UB-14, which at first glance would appear to be out of step with this discussion. However, a review of the lifting fuselage aircraft design objective and motivation shows a match with that for the flying wing concepts of the same time period. These concepts were characterized by thick airfoil shaped fuselages that were designed to produce a significant portion of the required lift. Another reason for including these concepts is their location in the ALV time line as depicted in figure 2. From their chronological location, it is possible that they greatly influenced both the lifting body and the flying wing work in the United States.

FLYING WING HISTORY

Since the beginning of manned flight, flying wing designs have been pursued with creativity, passion, and bravery by many visionaries. The early pioneers[60] of flight, beginning with Otto Lillienthal of Germany and including Alphonse Penaud of France, Clement Ader of France, and Jacob Ellehammer of Denmark, recognized the potential of an aircraft comprised primarily of a wing. A review of their work shows that the inspiration for much of the initial efforts came from observations of both plants and birds. In total, there have been well over 100 flying-wing, manned aircraft developed and flown by men from all parts of the world; yet, the only flying wing aircraft to ever achieve operational deployment is the Northrop Grumman B-2.

Presented in figure 4 is the time line of flying wing development for countries that have made significant contributions. The chart shows the dominance by Europe during the first half of the 20th century, as mentioned previously. In addition to the pioneering work in France, Germany, and England during this time period, notable accomplishments were also made in Switzerland, Denmark, and Austria. Russian contributions appeared during the 1930s but quickly ended around 1940.

The contributions from the United States have been sporadic as indicated by the solid and striped bars. The striped bars represent concepts that may have contributed to flying wing development, such as the lifting fuselage designs of Burnelli, noted by the bar extending from 1920 to 1940. The lifting-body work is represented by the bar extending from 1950 to 1980. Additional discussion on the lifting fuselage concept will be presented later in this section.

Another interesting trend in flying wing aircraft development is the history of the aircraft planform as shown in figure 5. Flying wing development was initially inspired by observations of nature, both in the form of plant seeds and birds. However, this concept quickly evolved to include planforms that are more recognizable today. By 1905, Dunne utilized untapered swept planforms in an effort to improve the stability characteristics of flying wings. In 1910, tapered and swept (arrow) planforms began to appear. The most aggressive use of the arrow wing planform is attributed to the Horten brothers of Germany. The use of the delta planforms for flying wings is attributed to Lippish in 1930. For present-day, flying-wing designs, the planform of choice is the arrow-wing planform, which allows for improved stability and control with high levels of aerodynamic performance.

As with most aircraft development activities, flying wing developments prior to 1950 were primarily a result of individual designers, whereas the work after 1950 may be characterized as corporate efforts involving many individuals and organizations. To highlight the contributions of the individual genius, the remaining portion of this section of the paper will concentrate on the work of individual aircraft designers prior to 1950.

A review of the historical contributions of the more than 30 prominent flying wing designers, prior to 1950, has identified six representative flying wing designers that have made unique and significant contributions. These designers also represent the diversity of countries involved in maturing this aircraft type, see table 2. Included in this list is Vincent Burnelli, inventor of the lifting fuselage concept, because of the apparent influence of his work on the flying wing development within the United States. Table 2 also lists the specific contribution made by each of the selected individuals.

Individual contributors, as a function of time, are depicted in figure 6. The figure also lists the country of each of the selected individuals. This chart shows that of the seven identified designers, three are from Germany and two each from both England and the United States. It is clear from the literature and available data, that Germany has led the development of the flying wing concept. The work of Lillienthal, Lippish, and the Horten brothers is impressive by all measures. The contributions of the English, Dunne and Hill, while not as diverse as the German influence is extremely notewothy in the area of stability and control. Contributions by Burnelli and Northrop of the United States focused on the maturation and commercial development of the flying wing concept.

The following subsections will provide additional details and insight into the specific contributions of the selected seven individuals and their countries. Note the information presented does not constitute detailed biographical and historical information on each of these individuals. Interested readers should pursue such information through the many recognized sources and experts.

German Flying Wings

The diversity of contributions by German aircraft designers to the development of the flying wing are represented by Lillienthal, Lippish, and Reimer and Walter Horten, see figure 7a, b, and c, respectively. The selection of these individuals is not intended to degrade the contributions of other notable German designers such as Alexander Soldenhoff (originally from Switzerland) and Jugo Junkers but to portray the general historical developments that came from Germany.

The history of German flying wing development, and in fact manned flight, begins with the inventor, builder, and pilot, Otto Lillienthal (1848 - 1896), see figure 7a. Lillienthal's interest in flight began in 1861 with the study of birds. In 1874, Otto Lillienthal and his brother, Gustav, showed the aerodynamic superiority of cambered airfoils. Their airfoil research continued until 1888 and was published in 1889. In 1889, Lillienthal turned his attention to aircraft design and built his first glider, which was used to assess lifting force, but it never flew. Lillienthal continued to invent, build, and pilot gliders from 1889 until his death in1896. During this time period, Lillienthal developed over 10 different aircraft. While Lillienthal's aircraft were not true flying wings, most of the designs had a nearly continuous planform comprised of the bird-like wing and a small aft-located horizontal surface. It is clear from the literature that the work of Lillienthal inspired most early flying wing development in Europe.

Alexander Lippish (1894-1976) is most noted for his work in developing the delta-planform, flying wings as depicted in figure 7b. Lippish began his flying wing development work in the late 1920s with the Storch series of gliders and then transitioned to powered flying wings and the Delta series of flying wings. Lippish's interest in the delta planform was directed at increasing the usable volume of his designs over that offered by the swept designs of that period. Lippish's pursuit of this design aspect is notable in Europe because most were consumed with proving or improving the flying wing concept. Between 1927 and 1945, Lippish developed over 13 flying wing aircraft, including the Delta I shown in figure 7b. Lippish is also noted for his interest in applying rocket power to flying wings as noted by the DM-1 design shown in the figure.

Perhaps the most prolific of the German flying wing developers were the Horten brothers, Reimer (1915-1993) and Walter (1913- 1994), see figure 7c[58,59,62,117-127]. Between 1931 and 1960 the Horten brothers developed over 20 flying wing aircraft, and as with both Lilienthal and Lippish, they began their work with gliders. And like Northrop in the United States, the Horten brothers are noted for their purist approach to the development of the flying wing. The Horten designs were extremely innovative in shape, controls, and construction. A representative Horten glider and powered flying wing, H XIIIa and H III respectively, are depicted in figure 7c. They were also the first to develop a turbo-jet powered flying wing.

England Flying Wings

The pioneering stability and control work of John Dunne (1875-1949) and the following work by Geoffrey Hill (1895-1964) characterize the primary contribution by England to flying wing development. As depicted in figure 8, Dunne's flying wing development occurred between 1907 and 1914 in which he produced more than 6 designs to investigate completely stable aircraft. Representative of Dunne's first design, a swept-wing tailless bi-plane, the Dunne D-8 of 1911 is shown in the figure. Dunne is credited with developing the first practical tailless aircraft. Following on the work of Dunne, Hill also pursued improved flight safety and stability through the development of flying wing aircraft. Hill developed a series of aircraft, named the Pterdactyls, between 1924 and 1930 as noted in figure 8. Hill's Pterdactyl Mk IV was the first tailless to roll and loop.

United States Flying Wings

As noted in figure 4, the flying wing development within the United States has been extremely sporadic, both pre-1950 and post-1950. The pre-1950 time period depicted in figure 4, which is the focus of this discussion, is represented by the work of Octave Chanute at the turn of the century, Vincent Burnelli (1895-1964), and Jack Northrop (1895-1981). This brief historical discussion will focus on the efforts of Burnelli[69-76] from 1919 to 1939 and Northrop[55-57,63-67] from 1940 to 1950 as presented in figure 9. At first glance, it is not obvious as to the relationship of Burnelli's work, shown in figure 9a, to the flying wing development, but upon further inspection, it is clear that both Burnelli and Northrop pursued the objective of bringing to market the most efficient aerodynamic shape, an all-lifting vehicle. Burnelli recognized the need to have the complete aircraft provide efficient lift in order to maximize payload capacity and range. Burnelli's design approach was to reshape the fuselage to achieve this goal. His efforts resulted in more than 10 operational designs, see figure 9a. It is clear that Burnelli never produced a flying wing design but his work with lifting fuselages and thick airfoils did contribute to the flying wing development. It is also interesting to note that the starting point for Northrop's flying wing efforts (left side of figure 9b) closely resembles the Burnelli UB-14 design shown on the right side of figure 9a.

Northrop's contribution to flying wing development, within the United States, is without dispute and is well documented. Like the Horten brothers of Germany, Northrop was a purist in his pursuit of the flying wing, which he labeled the All-Wing. It is believed that Northrop's introduction to the flying wing was through Tony Stadlman in the 1920s, while working at the Douglas Aircraft Company. Northrop matured his thoughts and in 1929 his Flying Wing (with tail) flew, see figure 9b. Northrop continued his flying wing development and in 1940 his first pure flying wing design took flight, the N-1M. From 1940 to 1950 Northrop produced more than 10 innovative designs that culminated with the YB 49 depicted in figure 9b. Northrop's contributions may be summarized as a complete aircraft designer in that all aspects of flying wing design were successfully considered in developing efficient and cost effective elegant designs.

UNITED STATES ALV HISTORY

The previous discussion has reviewed the pre-1950 development of the flying wing aircraft in an effort to clarify the role and contributions of various significant contributors. This section of the paper will draw upon those discussions to develop the ALV history. As mentioned previously, a review of the complete history ALVs shows that since 1950 the majority of both flying wing development as well as flying fuselage development has occurred within the United States. Thus, the following discussion on ALV history will concentrate on the work performed solely within the United States from 1920 to the present. A pictorial history of ALV development within the United States is presented in figures 10a through 10e.

It is with great interest that the United States ALV development begins with similar work by Burnelli, Staldman, and Northrop in the 1920s and 1930s, see figure 10a. Burnelli pursued the lifting fuselage concept for 20 years from 1919 to 1939 whereas Northrop did not see his initial flying wing (with tail) fly until 1929. By 1940 Northrop was beginning to develop a true flying wing aircraft as represented by the XB-35 shown in figure 10a. Additional discussion of these early contributions are provided above.

The interest in flying wings decreased significantly during the 1960s and 1970s as focus shifted from flight vehicle development to space vehicle development. The initial development of the lifting body concept is attributed to Alfred Eggers and H. Julian Harvey, in the early 1950s, who were conducting research on ballistic bodies for lifting reentry from orbital space flight[10,77-116]. The research of Allen and Eggers, along with a handfull of other NASA engineers, contributed to the body of knowledge in lifting-body aerodynamics, thermodynamics, and controls. However, it was not until the 1960s that a lifting-body, reentry vehicle was developed and flown, see figure 10b. The NASA lifting-body aircraft development activity grew out of a decision in the early 1960s, by the Scientific Advisory Board, to focus on winged reentry vehicles because of concerns of low speed control characteristics of lifting-body aircraft. This decision drove a number of individuals at NASA to independently explore the low speed flight characteristics of this class of vehicles. The success of these studies led to the eventual acceptance of lifting body designs as the preferred approach for reentry.

At the beginning of 1970s and extending into the 1980s, the effort of R. T. Jones, the well known aerodynamicists, to develop the oblique wing concept was a constant theme, as shown in figure 10c[27,128,129]. The effort by R. T. Jones coincided with the growing interest within the United States in the development of an efficient supersonic transport aircraft. It was proposed that an oblique flying wing is the optimum design for a supersonic transport but despite several sub-scale flight tests and extensive wind tunnel research the concept was never adopted by the industry. However, to this day, the oblique wing design remains the most creative ALV concept ever developed.

The 1980s and1990s signaled a new beginning in ALV design interest with the development of the Space Shuttle, B-2, and F-117, see figure 10d. It is interesting to note that these three ALV concepts were produced by 3 different companies indicating the acceptance and maturation of this design technology. At the time, the Space Shuttle reflected significant advancements in lifting body design technology and remains an outstanding performing vehicle today. Design of both the B-2 and F-117 reflect the growing influence of stealth design requirements and not the pursuit of the flying wing ALV concept that drove the work by Northrop in the 1940s. However, it is quite evident that the Space Shuttle design was greatly influenced by the body of work from the 60s and 70s just as the B-2 and F-117 designs were influenced of Northrop's flying wing designs of the 40s and 50s.

As we move into the new century, it is clear that the ALV concept remains the choice of future vehicles, see figure 10e. The figure show three distinctly different ALV concepts that are under development within the United States. In addition to these concepts for space travel (X-33), commercial transportation (BWB), and atmospheric research (PATHFINDER), there are a significant number of advanced ALV concepts under consideration for a variety of military missions. Also note, as with the Space Shuttle, B-2, and F-117 of figure 10d, each of these three concepts are under development by three different companies. This observation clearly indicate that after a century of development the ALV concept is finally being recognized as the design of choice.

To further explore the relationship between the various concepts discussed above, a time line of the Untied States ALV concepts is presented in figure 11. The chart segregates the lifting body, lifting fuselage, and flying wing categories for clarification. Also noted on the chart are bubbles indicating contributions from other countries. The relationships between the various contributors is represented by either a solid or dashed line where a solid line indicates a strong linkage and dashed line indicates a weak linkage. A review of this chart indicates that there is a strong linkage between the work of Burnelli, Stadlman, and Northrop prior to 1950. For the recent work there is a strong linkage between the pre-1950 work and the B-2 and BWB. Based upon these inferences and linkages, the time line chart of figure 11 is reformatted into the chart of figure 12 that reflects the historical time line for ALV development in the United States. Based upon this review, it is clear the technical leaders (individuals) in ALV development within the United States are Chanute, Stadlman, Burnelli, Northrop, Jones, and MacCready. Specific information on each of these individuals is presented in table 3. This is not to say that other individuals, teams, and organizations have not made significant contributions. The problem is that the corporate culture that exists in the aerospace industry make it extremely difficult to identify individual accomplishments.

HISTORICAL COMPARISONS

This final section of the paper will expand on the discussion presented at the end of the last section (see figure 12) in which the historical linkages between ALV concepts were identified. The study of these linkages is directed at understanding the lineage of the present day advanced ALV concepts in the hope of understanding how the past can assist in developing the future.

This assessment will be conducted for the Boeing Blended Wing Body (BWB), the Boeing/NASA X-43, and the MacCready PATHFINDER in figures 13, 14, and 15, respectively.

Presented in figure 13 are historical graphics and photographs of flying wing transport designs that are similar to the current state of the art BWB concept. The five historical designs selected for comparison to the BWB date from the 1940s. The similarity between all six concepts is clearly evident and quite striking. Each of the designs depicted were developed based upon similar classical goals: improved aerodynamic efficiency, increased payload, and reduced weight. Note that all six designs shown in the figure, with the exception of the B-2, have nearly identical propulsion system layout with the Junkers 1945 design being nearly identical to the BWB. The Burnelli design of 1951 also has winglets as does the BWB and an assessment of the aspect ratio for the various designs shows close similarity between the Horten design of 1948 and the BWB. A dichotomy of conclusions may be drawn from these observations that vary from: a good design is timeless, to the experience collected in the past is either unknown, forgotten, or at the least ill-judged.

A comparison of a historical high speed transport design of Burnelli from 1964 to the Boeing/NASA X-43 concept is presented in figure 14. As with the designs presented in the previous figure, there is a striking similarity between the 1964 design and the X-43. Both designs are characterized by a slab-like lifting body/fuselage, aft mounted delta wing, and twin vertical tails. The Burnelli design is unique in that it shows a canard and winglets on both the wing and canard. Even though there is a striking similarity in the two designs, the Burnelli concept is a supersonic cruise design whereas the X-43 is a hypersonic cruise design. This difference in design objective results in a broader function of the body for the X-43 design compared to the Burnelli concept. The X-43 design utilizes the body for both lift generation and as a pre-compression surface for the engine inlet flow whereas the Burnelli design is focused only on body lift generation. The same dichotomy of conclusions may be drawn from these observations.

Presented in figure 15 is a comparison of a variety of historical graphics of low sweep flying wing designs to the PATHFINDER. The four historical designs, selected for comparison to the Pathfinder, date from 1910 and include the first flying wing patent by Hugo Junkers (lower left of figure). However, unlike the striking similarity between the designs depicted in the previous two figures, there are significant differences between the low-sweep, flying wing designs shown. Also note that each of the four historical designs are for a large transport aircraft where the Pathfinder design is a very narrowly designed research vehicle. All five designs shown in the figure have nearly identical planform, with the Junkers 1910 flying wing design (bottom left) being nearly identical to the Pathfinder. The other three historical designs have a propulsion system layout that is similar to the Pathfinder, yet they differ from the Pathfinder design in that they have vertical surfaces for control. Also note that the Junkers design of 1910 and the Burnelli design of 1942 also have a separate horizontal control surface. Based upon this review, it may be concluded that a good design is timeless.

CONCLUDING REMARKS

The historical review of ALV indicates that we continue to re-create the past instead of learning from the past to create the future. These sentiments are clearly stated through the following quotes from A. R. Weyl, 1944.

"...Flying Wing, in which at the present period more interest than ever is being displayed."

"...it seems a fact that experience collected in the past with tailless aeroplanes is either unknown or forgotten or, at the least ill-judged..."

"...it is by no means sufficient that a crazy design flies; it must fly far better than everything else in order to raise attention among those closed circles..."

REFERENCES

1. Anderson, J. D. Jr.: A History of Aerodynamics and Its Impact on Flying Machines. 1997.
2. Angelucci, E.: Airplanes from the Dawn of Flight to the Present Day. 1971.
3. Bowers, P. M.: Unconventional Aircraft.
4. Chant, C.: Aviation an Illustrated History. 1980.
5. Gibbs-Smith, C. H.: Aviation - An Historical Survey from its Origins to the End of World War II. 1985
6. Lange, R. H.: Survey of Unconventional Aircraft Design Concepts. NVvL Symposium April 1987.
7. Lange, R. H.: Review of Unconventional Aircraft Design Concepts. AIAA Journal of Aircraft, vol. 25, no. 5, pp. 385 - 392. May 1988.
8. Maddock, I. A.: A History of Manned Powered Flying Wing Development: 1922-1999. SAE 199-01-5657. 1999 World Aviation Conference October 19-21, 1999.
9. Pinson, J. D.: Diamond Jubilee of Powered Flight; The Evolution of Aircraft Design. Dayton-Cincinnati Section AIAA with Air Force Museum. December 14-15, 1978.
10. Reed, D. B.: Wingless Flight, The Lifting Body Story. NASA SP-4220. 1997.
11. Rolfe, Dawydoff, Winter, Byshyn, and Clark: Airplanes of the World 1490 to 1969. 1969.
12. Roskam, J.: What Drives Unique Configurations. SAE Paper 881353, 1988.
13. Taylor, M. and Mondey, D.: Aircraft Facts & Feats. 1984.
14. Traylor, J. W. R.: Air Facts and Feats. 1974.
15. Wooldridge, E. T.: Winged Wonders The Story of the Flying Wings. 1983
16. Ankenbruck, H. O. and McKinney, M. O. Jr.: Generalized Performance Comparison of Large Conventional, Tail-Boom, and Tailless Airplanes. NACA TN No. 1477. October 1947.
17. Bicher, R. F. B. Jr,: Trends of Development in Flying Wing and Tailess Aircraft. USAF Wright Field Technical Report No. F-TR-101-DN, February 1946.
18. Brewer, G. W. and May, R. W. Jr.: Investigation of a 1/7-Scale Powered Model of a Twin-Boom Airplane and a Comparison of its Stability, Control, and Performance with Those of a Similar All-Wing Airplane. NACA TN 1649, 1948.
19. Brewer, G. W.: An Estimation of the Flying Qualities of the Kaiser Fleetwing All-Wing Airplane from Tests of a 1/7-Scale Model TED NO. NACA 2340, NACA RM No. L6J18, Nov. 1946.
20. Brewer, G. W. and Rickey, E. A.; Tests of a 1/7-Scale Powered Model of the Kaiser Tailless Airplane in the Langley Full-Scale Tunnel. NACA MR No. L6C13, 1946.
21. Buckstrom, A. A.: The Elements of Tailless Airplane Design. Sport Aviation, pp. 39-44, May 1979.
22. Campbell, J. P. and Seacord, C. L. Jr.: Determination of the Stability and Control Chasracterisitics of a Tailless All-Wing Airplane Model with Sweepback in the Langley Free-Flight Tunnel. NACA ACR No. L5A13. February 1945.
23. Cox, W. J., Siddall, J. N. and Stephenson, T. E.: A Tailless Research Aircraft. Aircraft Engineering. Pp. 184-190.
24. Dillworth, J. A.: Japanese Tailless Aircraft and Theoretical Work on Spiral Instability. USAF Wright Field Report No. F-IR-109-RE. August 1946.
25. Donlan, C. J.: An Interim Report on the Stability and Control of Tailless Airplanes. NACA Report No. 796.
26. Holbrook, C. T.: Some Studies of Flying Wings. Mississippi State College April a950.

27. Jones, R. T.: Notes on the Stability and Control of Tailless Airplanes. NACA TN 837, December 1941.

28. Kidd, E. A.: Longitudinal and Lateral Directional Stability Derivatives of the N-9MB Flying Wing Airplane as Obtained from Flight Tests. Cornell Aeronautical Laboratory, Report No. TB-559-F-1, October 1949.

29. Krinfeld, R.: Test Flying a Tailless Glider. The Aeroplane, pp 367-369, April 11, 1947.

30. Marske, J. J.: Handling and Performance Characteristics of Swept-Forward Flying Wing Aircraft. SAE Paper 750748, April 1975.

31. Murray, C. V.: Full Scale Research on a Flying Wing. Aircraft Engineering. Pp. 144-148.

32. Noggle, L. W. and Jobe, C. E.: Large-Vehicle Concepts. Astro. And Aero, vol. 17, April 1979, pp. 26-32.

33. Nonweiler, T. : German High Speed Aircraft and Guided Missiles Part II Guided Missiles. Report No. F.A. 251/2 Aerro 2071., Aug. 1945.

34. Pitkin, M. and Meggin, B.: Analysis of Factors Affecting Net Lift Increment Attainable with Trailing-Edge Split Flaps on Tailless Airplanes. NACA ARR No. L4I18. September 1944.

35. Seacord, C. L. Jr. and Ankenbruck, H. O.: Effect of Wing Modifications on the Longitudinal Stability of a Tailless All-Wing Airplane Model. NACA ACR No. L5G23. September 1945.

36. Seacord, C. L. Jr. and Ankenbruck, H. O.: Determination of the Stability and Control Chasracterisitics of a Straight-Wing,Tailless Fighter- Airplane Model in the Langley Free-Flight Tunnel. NACA ACR No. L5K05. February 1946.

37. Sone, R. W. Jr. and Hultz, B. E.: Summary of Spin and Recovery Characterisitics of 12 Models of Flying-Wing and Unconventional-Type Airplanes. NACA RM L50L29, March 1951.

38. Weyl, A. R.: The Biology of the Flying Saucer - I. The Aeroplane pp. 185-187. February 13, 1948.

39. Weyl, A. R.: The Biology of the Flying Saucer - II. The Aeroplane pp. 279-282. March 3, 1948.

40. Weyl, A. R.: The Biology of the Flying Saucer - III. The Aeroplane pp. 337-339. March 19, 1948.

41. Weyl, A. R.: The Biology of the Flying Saucer - IV. The Aeroplane pp. 385-387. April 2, 1948.

42. Weyl, A. R.: Stability of Tailless Aeroplanes. Aircraft Engineering, pp. 73-81, March 1945, pp. 103-111, April 1945.

43. Report of Wind Tunnel Tests on the Kaiser Flying Wing. Wind Tuinnel Report No. 590, Wright Brother Wind Tunnel M.I.T., May 1943.

44. Preview of the Future; the Armstrong Whitworth A. W. 52, Jan. 16, 1948.

45. Report H-81 Calculated Performance Kaiser Flying Wing Airplane. October 1943.

46. Tailless Research with Twin Jets. The Aeroplane pp. 73-777. February 16, 1948.

47. Lademann, R. W. E.: Development of Tailess and All-Wing Glidrs and Airplanes. NACA TM No. 666. April 1932.

48. Nickel, K. and Wohlfahart, M.: Tailless Aircraft in Theory and Practice. AIAA 1997.

49. Callaghan, J. T. and Liebeck, R. H.: Some Thoughts onb the Design of Subsonic Transport Aircraft for the 21st century. SAE Paper No. 901987. October 1990.

50. Liebeck, R. H., Page M. A., and Rawdon, B. K.: Blended-Wing-Body Subsonic Commercial Transport. AIAA 98-0438. January 1998.

51. Liebeck, R. H., Page, M. A., Rawdon, B. K., Scott, P. W., and Wright, R. A.: Concepts for Advanced Subsonic Transports. NASA CR 4624, September 1994.

52. Potsdam, M. A., Page, M. A., and Liebeck, R. H.: Blended Wing Body Analysis and Design. AIAA-97-2317.

53. Whitehead, R. E.: Subsonic Transportation, Presentation to the Aeronautics Advisory Committee. NASA Office of Aeronautics and Space Technology. October 21, 1992.

54. Weyl, A. R.: Tailless Aircraft and Flying Wings-A Study of Their Evolution and Their Problems. Aircraft Engineering, pp. 340-352, December 1944, pp. 8-12, January 1945, pp. 41-46, February 1945.

55. Allen, R. S.: The Northrop Story; 1929-1939. New York; Orion, 1990.

56. Anderson, F.: Northrop: An Aeronautical Nistory. Los Angelas; Northrop. 1976.

57. Begin, L.: The Northrop Flying Wing Prototypes. AIAA Paper 83-1047, 1983.

58. Horten, R. and Selinger, P. F.: Nurflugel - Die Geschichte der Horten-Flugzeuge 1933-1960. 1983.

59. Kohn, L.: The Flying Wings of Northrop. Milwaukee: Aviation Publications. 1974.

60. Longyard, W. H.: Who's Who In Aviation History: 500 Biographies.

61. McLarren, R.: Low Drag Accented in All-Wing. Aviation Week. Dec. 20, 1948.

62. Myhra, D.: The Horten Brothers and Their All-Wing Aircraft. 1998.

63. Northrop, J. K.: The Development of All-Wing Aircraft. 35th Wilbur Wright Memorial Lecture. The Royal Aeronautical Society Journal, Vol. 51, pp. 481-510, 1947.

64. Northrop, J.: The Northrop XB-35 Flying Wing Superbomber. Aviation, Aug. 1946.

65. Northrop, J.: The All-Wing Type Aircraft. Aviation, 29 March 1930.

66. Pape, G. and Campbell, J.: Northrop Flying Wings: A History of Jack Northrop's Visionary Aircraft. Atglen, PA: Schiffer, 1995.

67. Sears, W. R.: Flying Wing Airplanes: The XB-35/YB-49 Program. AIAA Paper 80-3036, 1980.

68. Von Karmen, T. and Edson, L.: The Wind and Beyond: Theodore von Karmen. Boston: Little Brown. 1967.

69. Feigenbaum, D.: Estimation of the Performance and Longitundianl Stability and Control of a Lifting-Body Type of Cargo Airplane from Tests of Simplified Models. NACA Wartime Report MR No. L5EO9a. L-541. June 1945.

70. Harris, T. A.: Wind Tunnel Tests of 1/7-Scale Model of the Burnelli Single Boom Attack Bomber, X-18-B1. NACA CR 1105.5 Burnelli 18B-1/1. June 16 1939.

71. Jacobs, E. N. and Sherman, A: Wing-Fuselage Interference - Comparison of Conventional and Airfoil-Type-Fuselage Combinations. NACA Wartime Report L - 509 ARC March 1937

72. Klemin, Alexander, and Ruffner, Benjamin: Lift Slope and Distribution on Burnelli Aeroplanes. The Aircraft Engineer, vol. XII, no. 6, (Supp. To Flight) June 18, 1936, pp. 652a-652c.

73. Laitone, E. V.: A High-Speed Investigation of the Burnelli XB-AB-3 Model in the N.A.C.A. 8-Foot High-Speed Wind Tunnel. NACA Report 1105.5:Burnelli/BAB-3/2. June 19, 1940.

74. Neihouse, A. I. and Harmon, S. M.: Spin Tests of a 1/24-Scale Model of the Burnelli XB-AB-3 Airplane. NACA CR 1105.5 Burnelli BAB-3/1. August 2, 1940.

75. Wenzinger, C. J. and Harris, T. A.: Wind Tunnel Tests of 1/7-Scale Model of the Burnelli Twin Boom Attack Bomber, XB-17-B1. NACA CR 1105.5 Burnelli 17B-1/1. May 8, 1939.

76. 1105.5; Burnelli/BAB-3/3. XB-AB-3 wind tunnel model coordinates. Burnelli Aircraft Company. Guggenheim School of Aeronautics. Report on Wind Tunnel Test No. 687-H. October 25, 1937.

77. Allen, H. J. and Eggers, A. J.: A Study of the Motion and Aerodynamic Heating of Missiles Entering the Earths Atmosphere at High Supersonic Speeds. NACA RM A53D28, 1953.

78. Allen, H. J. and Eggers, A. J.: A Study of the Motion and Aerodynamic Heating of Missiles Entering the Earths Atmosphere at High Supersonic Speeds. NACA TN 4047, 1957.

79. Allen, H. J. and Eggers, A. J.: A Study of the Motion and Aerodynamic Heating of Missiles Entering the Earths Atmosphere at High Supersonic Speeds. NACA Report, 1958

80. Bertram, M. H. and McCauley, W. D.: An Investigation of the Aerodyanmic Characteristics of Thin Delta Wings with a Symmetrical Double-Wedge Section at a Mach Number of 6.9, NACA RM L55B14, 1955.

81. Cruz, C. I. and Ware, G. M.: Control Effectiveness and Tip-Fin Dihedral Effects for the HL-20 Lifting Body Configuration at Mach Numbers From 1.6 to 4.5. NASA TM 4697, 1995.

82. Dennis, D. H. and Cunningham, B. E.: Forces and Moments on Inclined Bodies at Mach Numbers from 3.0 to 6.3. NACA RM A54E03, 1954.

83. Dennis, D. H. and Cunningham, B. E.: Forces and Moments on Pointed and Blunt-Nosed Bodies of Revolution at Mach Numbers from 2.75 to 5.00. NACA RM A52E22, 1952.

84. Eggers, A. J, Hansen, C. F., and Cunningham, B. E.: The Effect of Yaw and Heat Transfer to a Cylindrical Stagnation region in Hypersonic Flow. NACA RM A55E02, 1955.

85. Eggers, A. J. and Syvertson, C. A.: Aircraft Configurations Developing High Lift-Drag Ratios at High Supersonic Speeds. NACA RM A55L05, 1956.

86. Eggers, A. J., Resnikoff, M. M. and Dennis, D. H.: Bodies of Revolution Having Minimum Drag at High Supersonic Airspeeds. NACA Report 1306, 1957.

87. Eggers, A. J. and Syvertson, C. A.: Experimental Investigation of a Body Flare for Obtaining Pitch Stability and a Body Flap for Obtaining Pitch Control in Hypersonic Flight. NACA RM A54J13, Jan. 1955.

88. Eggers, A. J., Allen, H. J., and Neice, S. E.: A Comparative Analysis of the Performance of Long-Range Hypervelocity Vehicles. NACA RM A54L10, March 1955.

89. Eggers, A. J. and Savin, R. C.: Approximate Methods for Calculating the Flow about Nonlifting Bodies of Revolution at High Supersonic Airspeeds. NACA TN 2579, Decmebr 1951.

90. Epstein, P. S.: On the Air resistance of Projectiles. Proceedings of National Academy of Sciences, 1931, vol. 17, pp. 532-547.

91. Ferrari, C.: The Determination of the Projectile of Minimum Wave Resistance. Reale Academia della Science de Torino Atti. 1939

92. Flax, A. H. and Lawrence, H. R.: The Aerodynamics of Low Aspect Ratio Wings and Wing-Body Combinations. CAL Report No. CAL-37, 1951.

93. Gowen, F. E. and Perkins, E. W.: Drag of Circular Cylinders for a Wide Range of Reynolds Numbers and Mach Numbers. NACA TN 2960, 1953.

94. Grimminger, G., Williams, E. P., and Young, G. B. W.: Lift on Inclined Bodies of Revolution in Hypersonic Flow. Jour Aero. Sci., vol. 17, no. 11, Nov. 1950, pp. 675-690.

95. Hodges, A. J.: The Drag Coefficient of Very High Velocity Spheres. Jour. Aero. Sci., vol. 24, no. 10, Oct. 1957, pp. 755-758.

96. Hsue-Shen Tsien: Supersonic Flow Over an Inclined Body of Revolution. Journal of Aero. Sci., 1938, pp. 480-483.

97. Jack, J. R. and Gould, L. I.: Aerodynamics of Slender Bodies at Mach Number of 3.12 and Reynolds Numbers from 2x10 to 15x10 - II - Aerodynamics Load Distributions of Series of Five Bodies Having Conical Noses and Cylindrical Afterbodies. NACA RM E52C10, 1952.

98. Klunker, E. B. and Harder, K. C.: Some Considerations of the Influence of Body Cross-Sectional Shape on the Lifting Efficiency of Wing-Body Combinations at Supersonic Speeds. NACA RM L56H30, 1956.

99. Lazzeroni, F. A: Investigation of a Missile Airframe with Control Surfaces Consisting of Projecting Quadrants of the Nose Cone. NACA RM A53L21, 1954.

100. Lighthill, M. J.: Supersonic Flow Past Bodies of Revolution. R&M No. 2003, British ARC 1945.

101. Malina, F. J. and Summerfield, M.: The Problem of Escape from the Earth by Rocket. Jour. Aero. Sci., vol. 14, no. 8, Aug. 1947, pp. 471-480.

102. Moeckel, W. E.: Flow Separation Ahead of a Blunt Axially Symmetric Body at Mach Numbers 1.76 to 2.10. NACA RM E51125, December 1951.

103. Moeckel, W. E.: Flow Separation Ahead of Blunt Bodies at Supersonic Speeds. NACA TN 2418, 1951.

104. Osborne, R. S. and Wright, J. B.: Tests of Lifting Surfaces on Conical and Cylindrical Portions of a Body at Supersonic Mach Numbers and at a Mach Number of 1.2. NACA RM L9F29, 1949.

105. Penland, J. A.: Aerodynamic Characterisitics of Circular Cylinders at Mach Number 6.86 and Angles of Attack up to 90°. NACA RM L54A14, 1954.

106. Resnikoff, M. M.: Optimum Lifting Bodies at high Supersonic Airspeeds. NACA RM A54B15, May 1954.

107. Sears, W. R.: On Projectiles of Minimum Wave Drag. Quart. Of Applied Math, Vol. IV, no. 4, Jan. 1947, pp. 361-366.

108. Seiff, A. and Allen, H. J.: Some Aspects of the Design of Hypersonic Boost-Glide Aircraft. NACA RM A55E26. Aug. 1955.

109. Seiff, A., Sandahl, C. A., Chapman, D. R., Perkins, E. W., and Gowen, F. E.: Aerodynamic Characterisitcs of Bodies at Supersonic Speeds - A Collection of Three Papers. NACA RM A51J25, Nov. 1951.

110. Sibulkin, M.: Heat Transfer Near the Forward Stagnation Point of a Body of Revolution. Jour. Aero. Sci., vol. 19, no. 8, Aug, 1952, pp. 570-571.

111. Van Dyke, M. D.: Practical Calculation of Second-Order Supersonic Flow Past Nonlifting Bodies of Revolution. NACA TN 2744, July 1952.

112. Vincenti, W. G. and Wagoner, C. B.: Transonic Flow Past a Wedge Profile with detached Bow Wave. NACA Report 1095, 1952.

113. Von Karman, T. and Moore, N. B.: Resistance of Slender Bodies Moving With Supersonic Velocities, With Special Reference to Projectiles. Transaction of the American Society of Mech Engr. APM-54-27, 1932.

114. Ward, G. N.: Supersonic Flow Past Slender Pointed Bodies. Quart. Jour. Mech. and Appl. Math, Vol. II, pt. 1, March 1949, pp. 75-99.

115. Ware, G. M. and Cruz, C. I.: Aerodynamic Characterisitics of the HL-20. Journal of Spacecraft And Rockets, vol. 30, no. 5, Sept-Oct 1993, pp. 529-536.

116. Perkins, E. W., Jorgensen, L. H., and Sommer, S. C.: Investigation of the Drag of Various Axially Symmetric Nose Shapes of Fineness Ration 3 for Mach Numbers from 1.24 to 7.4. NACA Report 1386. 1958.

117. Biot, M. A. and Jayne, J. M.: Horten Tailless Aircraft. Office of the Publication Board, Dept. of Commerce Report No. 258.

118. Dabrowski, H-P: Flying Wings of the Horten Brothers. Schiffer Military/Aviation History. 1995.

119. Horten Brothers: Ten Years Development of the Flying-Wing High Speed Fighter. Chance Vought Aircraft Report No. LGB 164.

120. Horten: Flying Wing Interceptor. CN-153578, March 1945.

121. Kluge, R. W. and Fay, C. L.: German High Speed Airplanes and Design Developments. Aug. 1945.

122. LeBlanc, N.: German Flying Wings Designed by the Horten Brothers. USAF Wright Field Report No. F-SU-1110-ND, Jan. 1946.

123. Nauber: Comparisons of the 8-229 and the GO P-60 All-Wing Airplanes. USAF Wright Field No. 525. February 1946.

124. Quick, A. W.: Flight Characteristics of the Swept-Back Wing at Small Velocities. GEHEIM P37. 1943.

125. Schmid: Tentative Description of Construction of Flying Wing 229. USAF Wright Field No. 526. April 1946.

126. Wilkinson, K. G.: The Horten Tailless Aircraft. R.A.E. Technical Rpt. No. 1703. October 1945.

127. Theories About Tailless Airplanes. USAF Wright Field No. 516. February 1946.

128. Jones, R. T.: Estimated Lift-Drag Ratios at Supersonic Speed. NACA TN 1350. July 1947.

YEAR	FLYING WING	LIFTING FUSELAGES	LIFTING BODY
0	Quetzalcoatlus northropi Zanonia Seed observed		
1800-1819			
1820-1839			
1840-1859			
1860-1879	Penaud, 1876		
1880-1889			
1890-1899	Etrich Gliders, 1890 Ader, Eole, 1890 Otto Liliental, 1891 Chanute, 1896		
1900-1904	Jatho, 1903 Ellehammer, 1906		
1905-1909	Etrich Zanonia-Wing Glider,1907 Dunne D-1.A, 1907 Etrich I, 1908 Dunne D3, D4 , 1907		
1910-1914	Dunne, D.6, 1910 Dunne, D.8, 1912 Junkers, 1913 U.S. Army Burgess Dunne, 1914		
1915-1919		Remington Burnelli RB-1, 1919	
1920-1924	Lippisch-Espenlaub Glider, 1921 Wenk, Wenltenseyler, 1921 Tscheranovsky, 1924	Remington Burnelli RB-2, 1922 de Monge, 7.4, 1924	
1925-1929	Westland Hill Pterodactyl, 1925 Hill Tailess, 1926 Tscheranovsky, 1926 Lippisch Storch IV, 1926 Lippisch Storch I, 1927 Lippisch Storch V, 1929 Scroggs Dart, 1929 Soldehoft A2, 1929	Dyle & Bacalan D.B. 10, 1926 Burnelli CB-16, 1927 Avion, Northrop Flying Wing, 1929	

Table 1. Chronological listing of all lifting vehicles concepts.

YEAR	FLYING WING	LIFTING FUSELAGES	LIFTING BODY
1930-1934	Lippisch Delta 1, 1930 Junkers, G-38, 1930 Fauvel AV2, 1930 Soldehoft A4, 1931 Horten Ho I, 1933 Arup No. 1,2,3,4, 1932 Westland Hill, 1934 Tcheranovsky Blch-3, 1934	Burnelli VB-20, 1930	
1935-1939	Horten Ho II, 1935 Waterman Arrowplane, 1935 Canova All-Wing, 1935 Horten Ho V, 1936 Waterman Arrowbile, 1937 Japanese, HK-1, 1938 Horten Ho III, 1938 Tcheranovsky Blch-20, 1938 Handley Page HP 75 MANX, 1938	Burnelli UB-14, 1935 Burnelli CBY-3, 1939	
1940-1944	Horten Ho IV, 1940 Lippisch DFS 194, 1940 Northrop N1M, 1940 Japanese, KU-2, 1941 Japanese, KU-3, 1941 Northrop N9M, 1942 Vought V-173, 1942 Handley Page Manx, 1943 Messerschmitt Me163 Komet,1943 Horten Ho VII, 1943 Northrop XP-56, 1943 Horten Ho XIII, 1943 Horten Ho VI, 1944 Horten Ho XII, 1944 Northrop MX324/334, 1944		
1945-1949	Horten/Gotha Ho IX, 1945 Northrop XP-79B, 1945 Lippish DM-1, 1945 Japanese, J8M1, 1945 G.A.L./56, 1946 Northrop XB-35, 1946 Northrop YB-49, 1947 Horton Ho Xva, 1948 Whitworth A. W. 52, 1948		
1950-1954	Horton Colibri Ho XVI , 1950 De Haviland DH 108, 1950 Northrop X4, 1950 Chance Vought, 1950 Chance Vought CV-XF5U-1, 1950 Fauvel AV-36, 1951 Saab 35 Draken, 1951 Avro 698, 1953 Horton Motorglider, 1953 Horten HW-X-26-52, 1954		
1955-1959			
1960-1964	Mitchel Wing B10, 1960 Horton I/Ae.38, 1960 Hadley Page Slewed Wing, 1961		NASA M2-F1, 1963
1965-1969	Dyke JD-1 Delta, 1965	Dyke JD-1 Delta, 1965	NASA M2F2, 1966 NASA HL-10, 1966 NASA X-24A, 1969
1970-1974	Rogallo Wings, 1970		NASA M2F3, 1970 NASA X-24B, 1973
1975-1979	Sawyer Skyjacker, 1975		
1980-1984	Lockheed F117		
1985-1989	Horton Pulio, 1987 Northrop B-2, 1988		
1990-1994	McDonnell Douglas A10		
1995-1999	Lkhd/Martin A17		Lockheed X-38
2000-2004			Lockheed X-33

Table 1. Concluded.

Lilienthal: (1848-1896)	Developed first all wing glider. First sustained controlled flight in history.
Dunne: (1875-1949)	First to address flying wing S&C issues.
Burnelli: (1895-1964)	Developed lifting fuselage concept for large payload and volume.
Hill: (1895-1956)	First successful practical tailless aircraft. Resolved S&C and stalling of flying wing.
Lippish: (1894-1976)	Developed delta flying wing concepts.
Horten: (1913-1994)	Developed arrow flying wing concepts.
Northrop: (1895-1981)	Matured the flying wing concept.

Table 2. Listing of flying wing primary contributors.

Chanute: (1832-1910)	Brought Lilienthal's (flying wing) work to U.S.
Staldman: (1885-1982)	First advocate for flying wing aircraft in U.S.
Burnelli: (1895-1964)	Developed lifting fuselage concept.
Northrop: (1895-1981)	Matured flying wing concept.
R. T. Jones:	Developed oblique wing concept.
MacCready:	Developed advanced UAV concept.

Table 3. Primary individual contributors to the United States all-lifting-vehicle concepts.

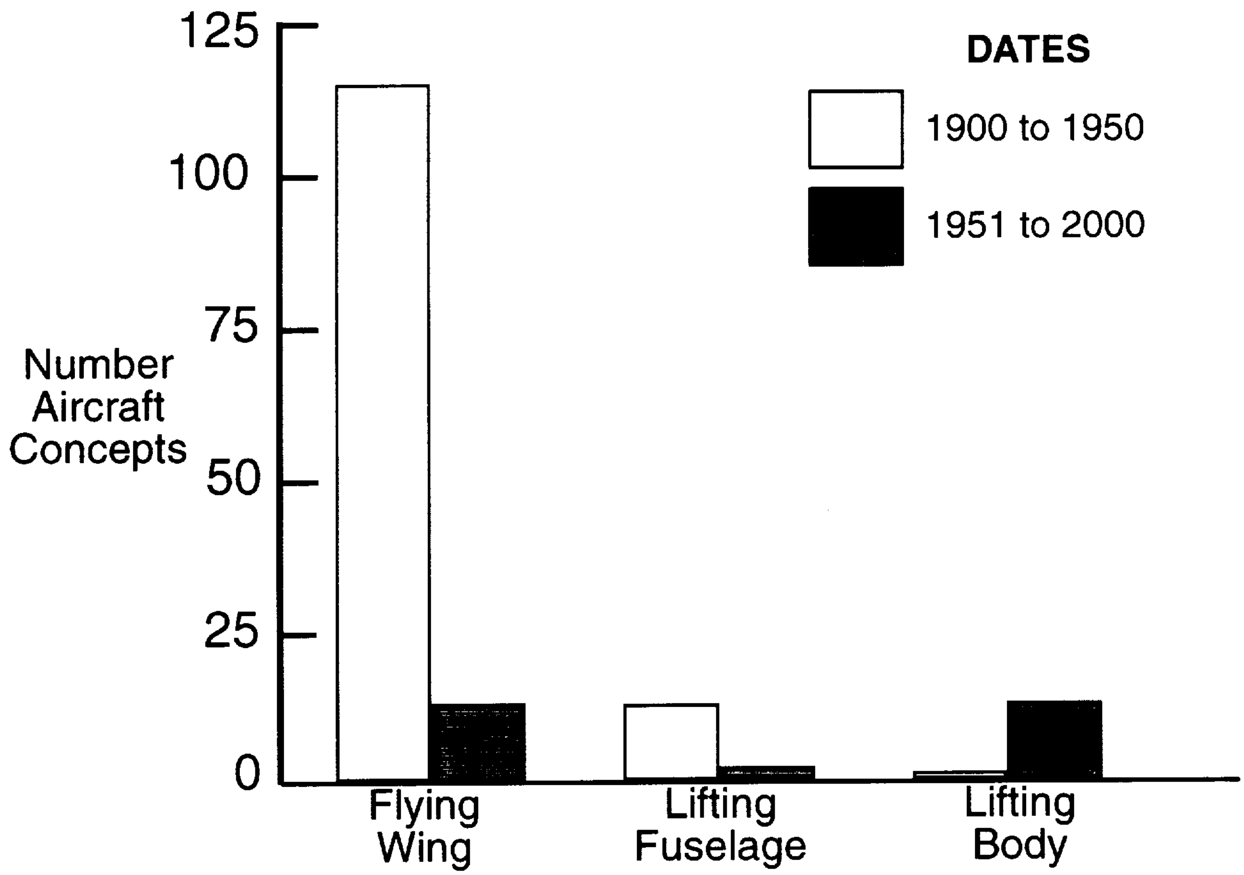


Figure 1. Number of all-lifting-vehicle aircraft developed since 1900.

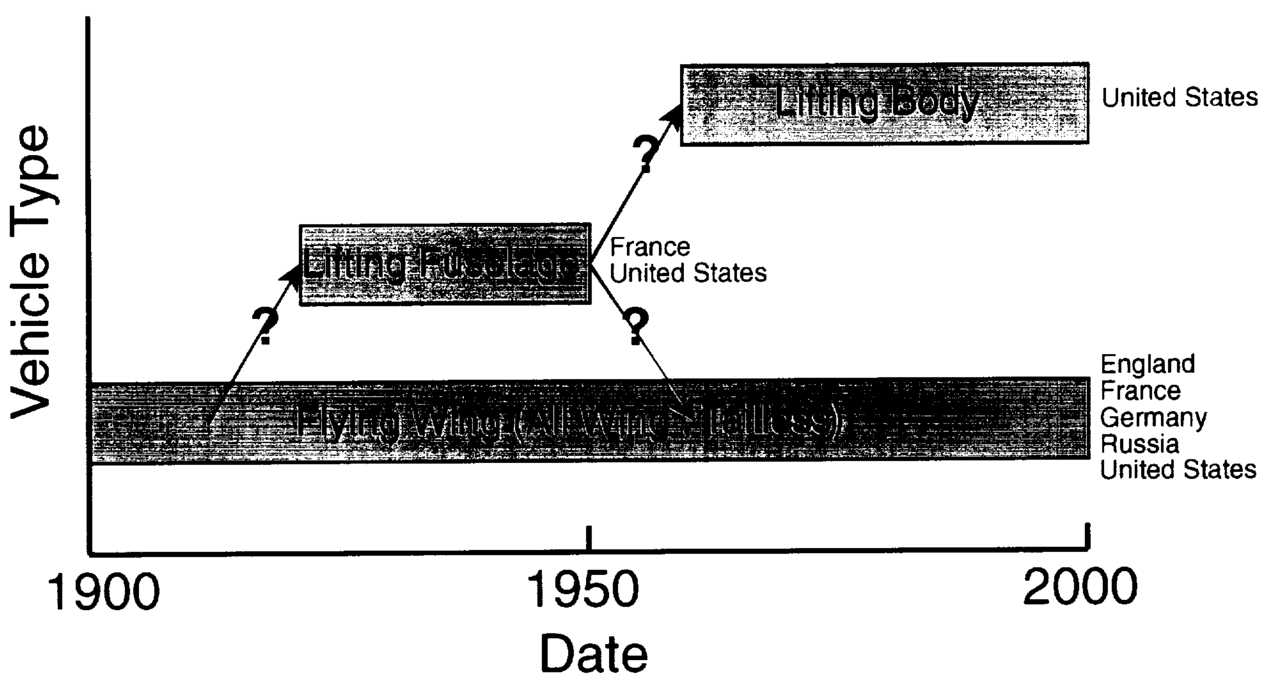


Figure 2. Development time line for each type of all-lifting-vehicle aircraft .

FLYING WING
Northrop, B-2, 1980

LIFTING FUSELAGE
Burnelli, UB-14, 1934

LIFTING BODY
NASA/Northrop, M2-F2, 1966

Figure 3. Representative ALV concepts.

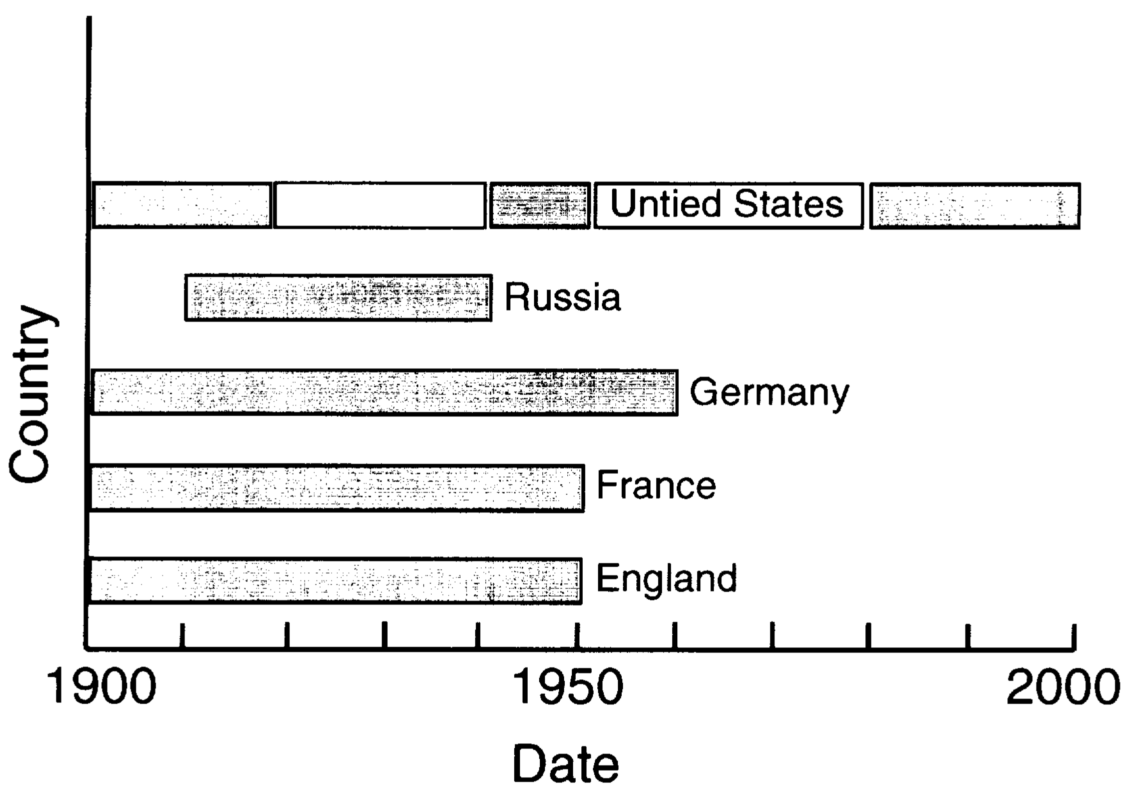


Figure 4. Development time line for each of the primary contributing countries of flying wing aircraft .

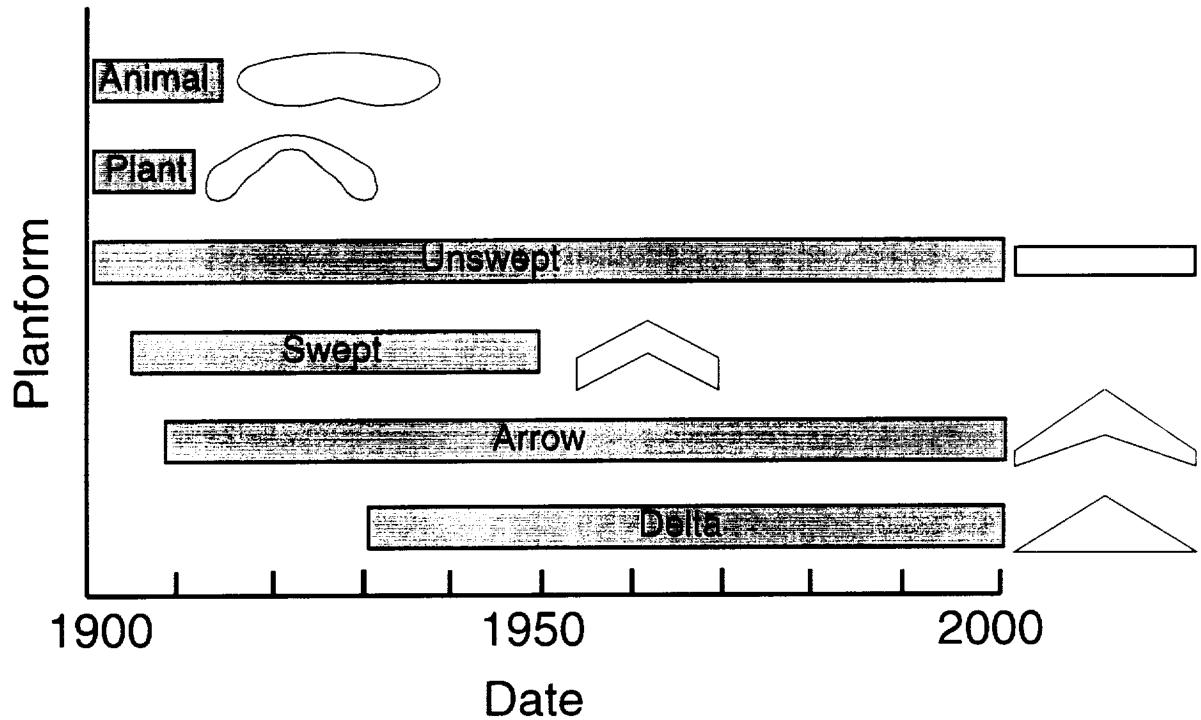


Figure 5. Development time line for each type flying wing planform.

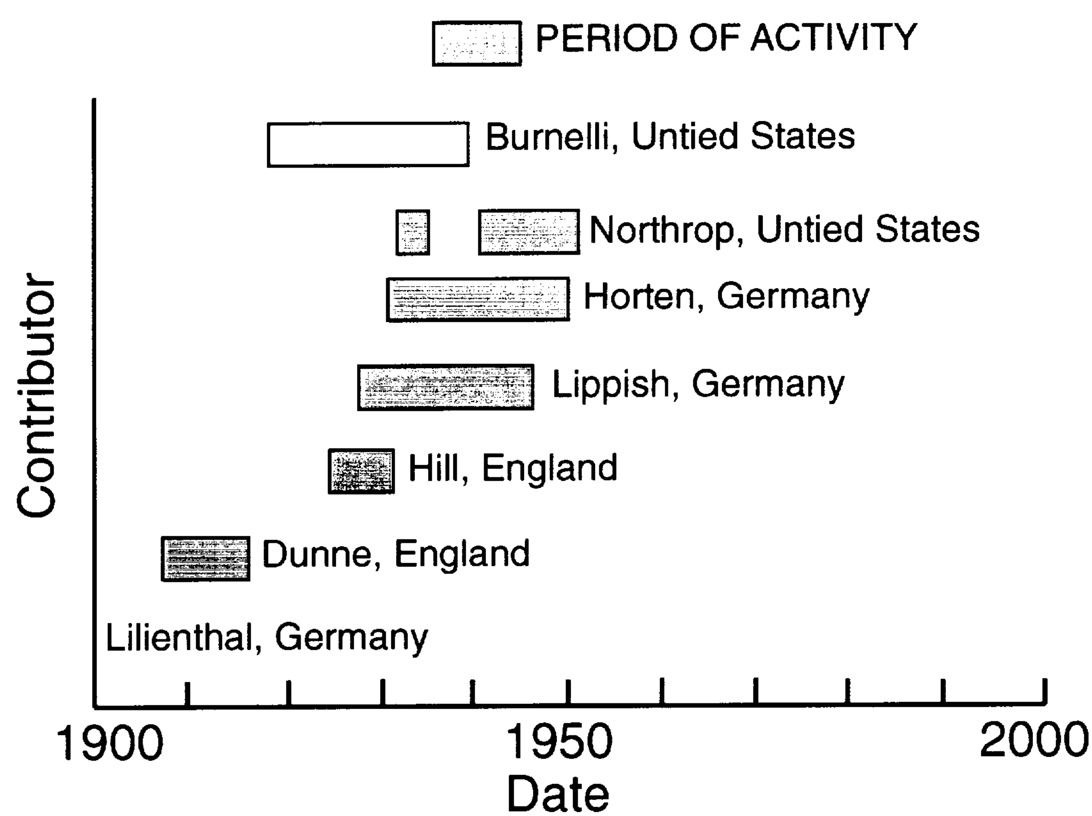
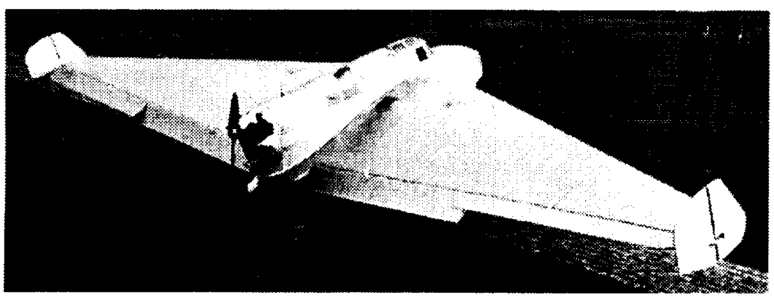


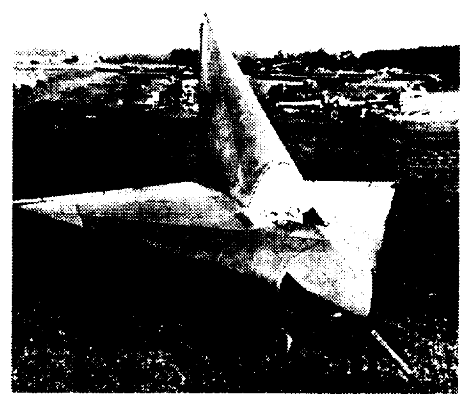
Figure 6. Development time line for the primary contributors to the flying wing concept.

No. DESIGNS: ~ 17

(a) Otto Lillienthal

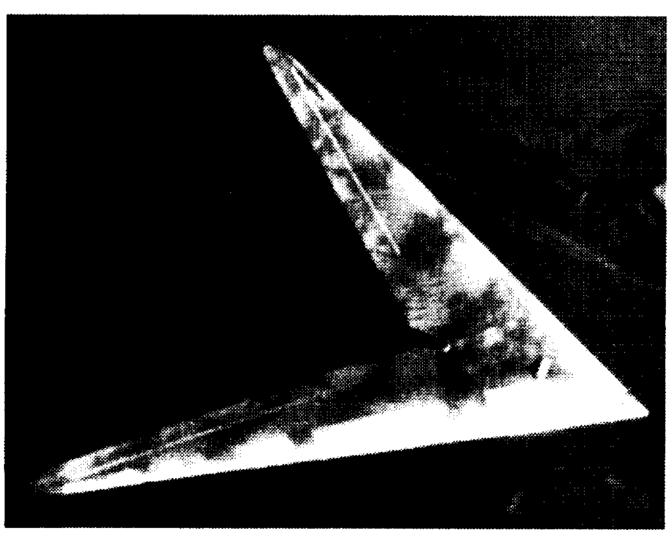


Delta I

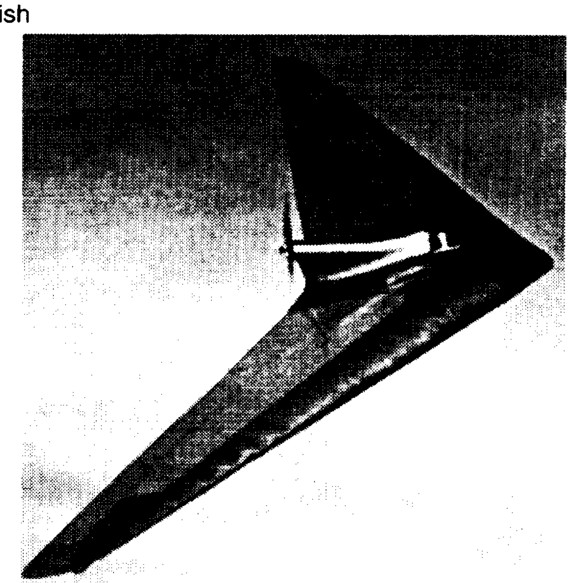


DM- I

(b) Alexander Lippish



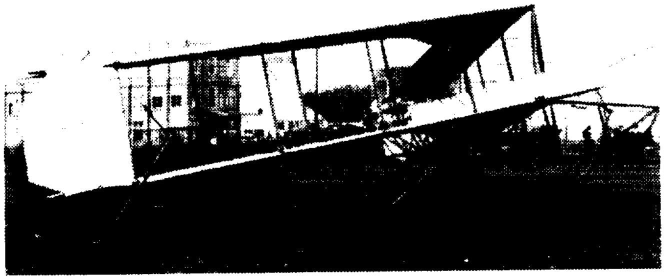
H-XIIIa



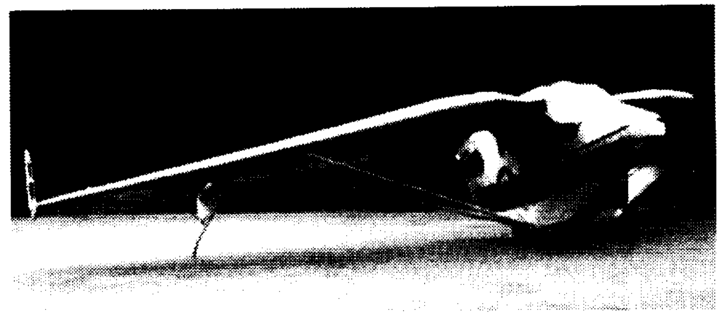
H-III

(c) Reimer and Wilber Horten

Figure 7. Germany's primary contributors of flying wing aircraft.

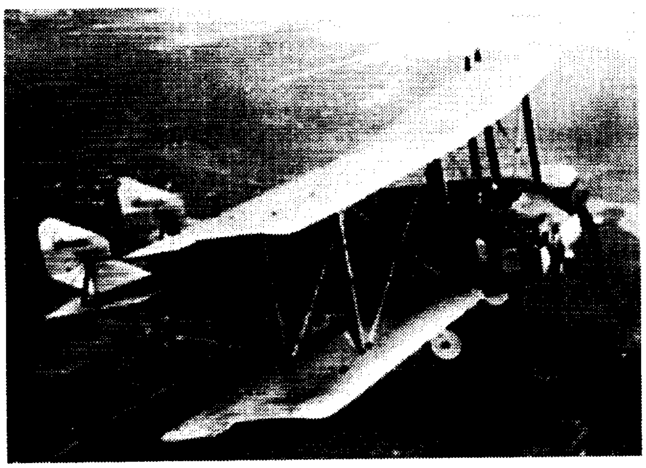


John Dunne - D 8



Geoffrey Hill - Pterodactyl Mk 1

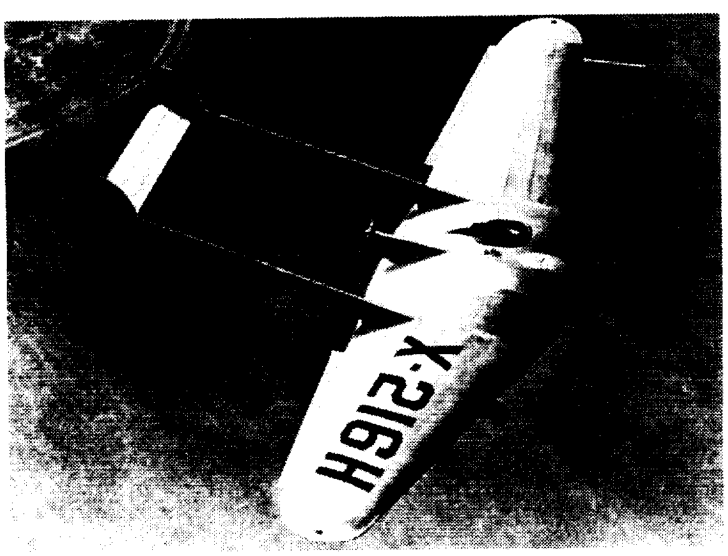
Figure 8. England's primary contributors of flying wing aircraft.



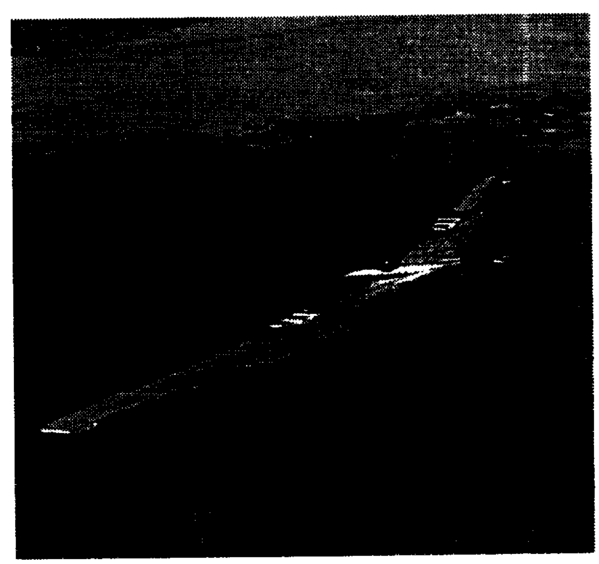
RB - 1

UB - 14

(a). Vincent Burnelli



Flying Wing

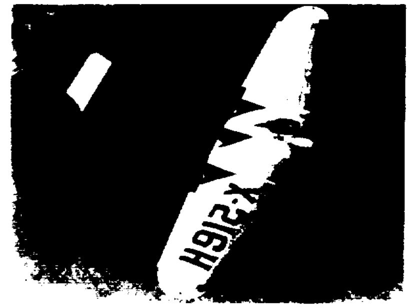


YB - 49

(b). Jack Northrop.

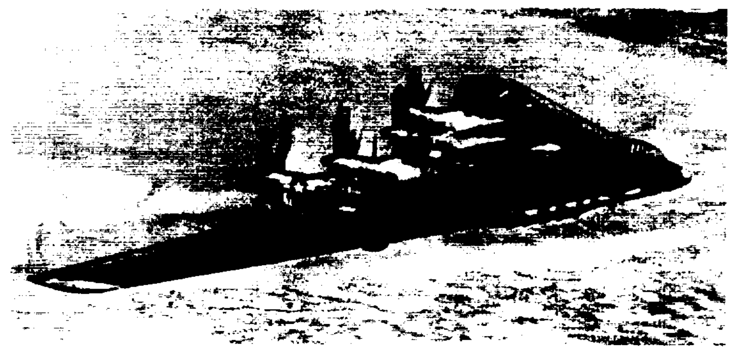
Figure 9. United States primary contributors of flying wing aircraft.

Burnelli, UB-14
Lifting Fuselage



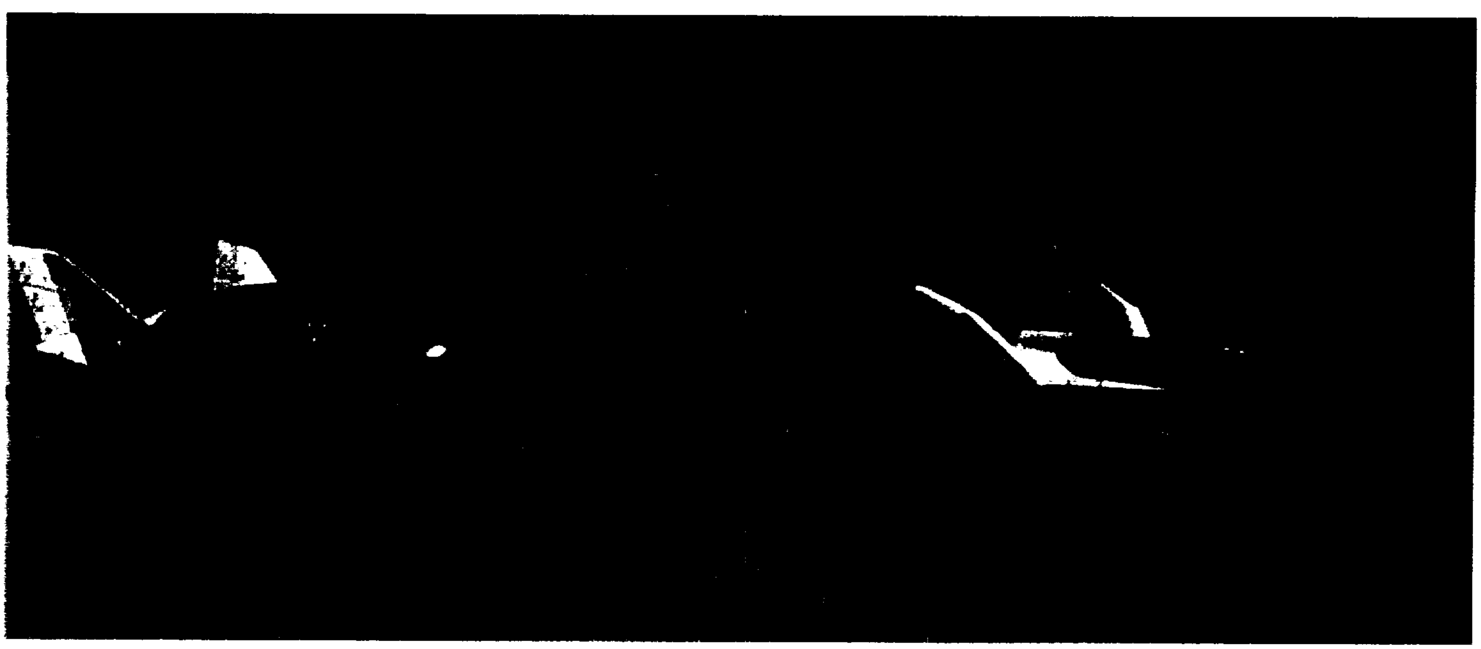
Northrop, Flying Wing

Stadlman



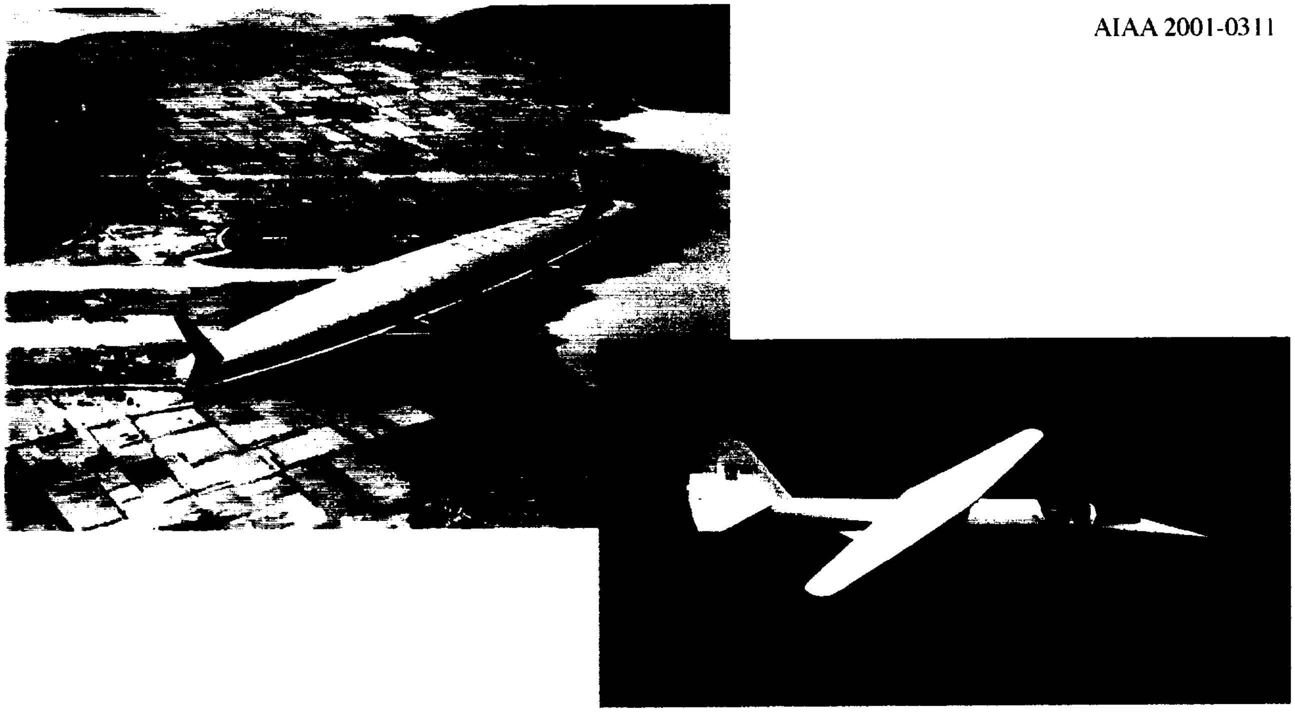
Northrop, XB-35
Flying Wing

(a) Lifting Fuselage and Flying Wing, 1920 to 1950.



(b) Lifting Body, 1960 to 1970.

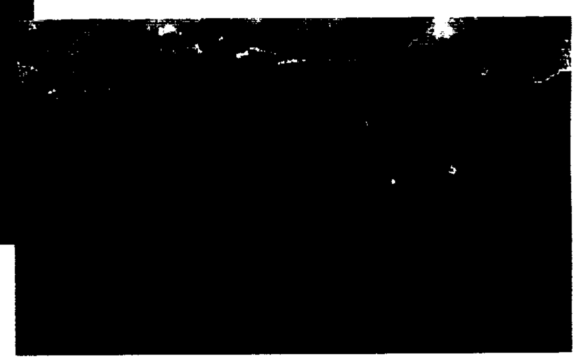
Figure 10. Diversity of United States all-lifting-vehicle aircraft .



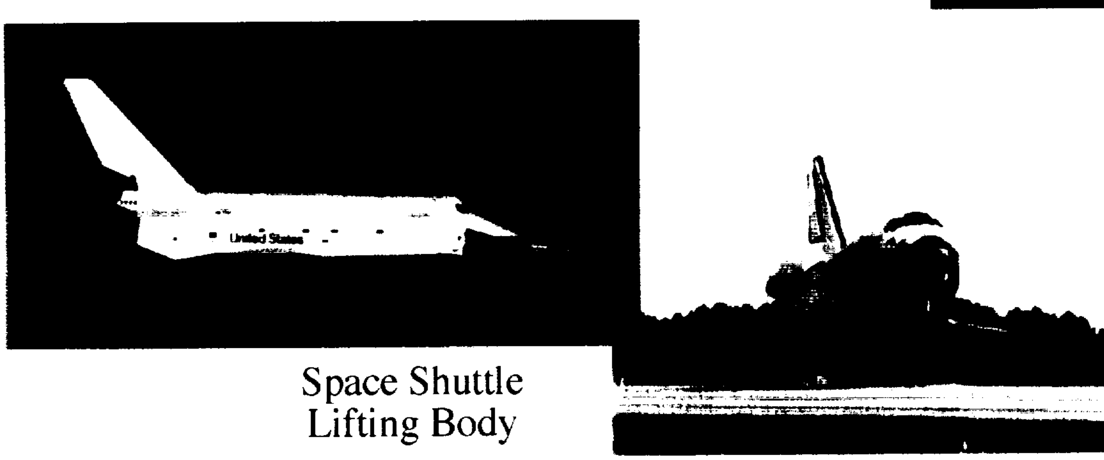
R. T. Jones, AD-1

(c) Oblique Flying Wing, 1970 to 1980.

B-2
Flying Wing



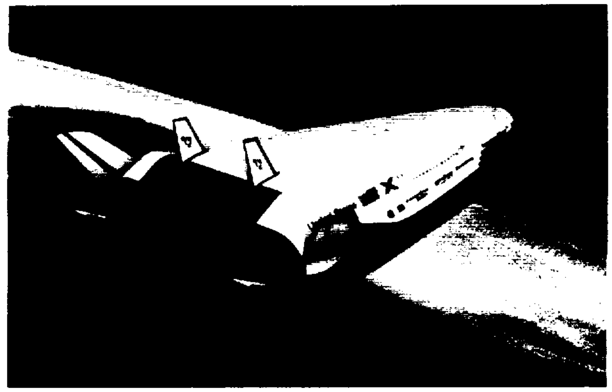
F-117
Flying Wing



Space Shuttle
Lifting Body

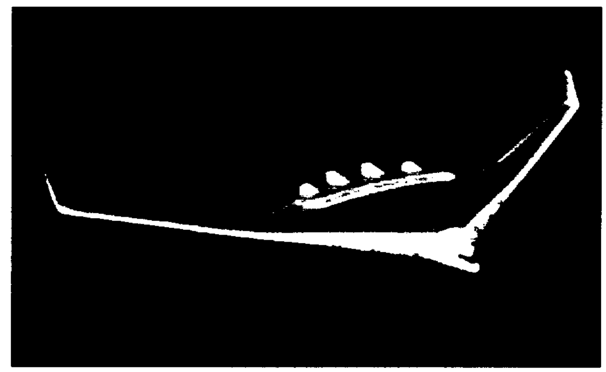
(d) Flying Wing and Lifting Body,1980 to 1990.

Figure 10. continued .



X-33
Lifting Body

Pathfinder
Flying Wing



Blended Wing Body (BWB)
Flying Wing

(e) Flying Wing and Lifting Body, 1990 to 2000.

Figure 10. concluded.

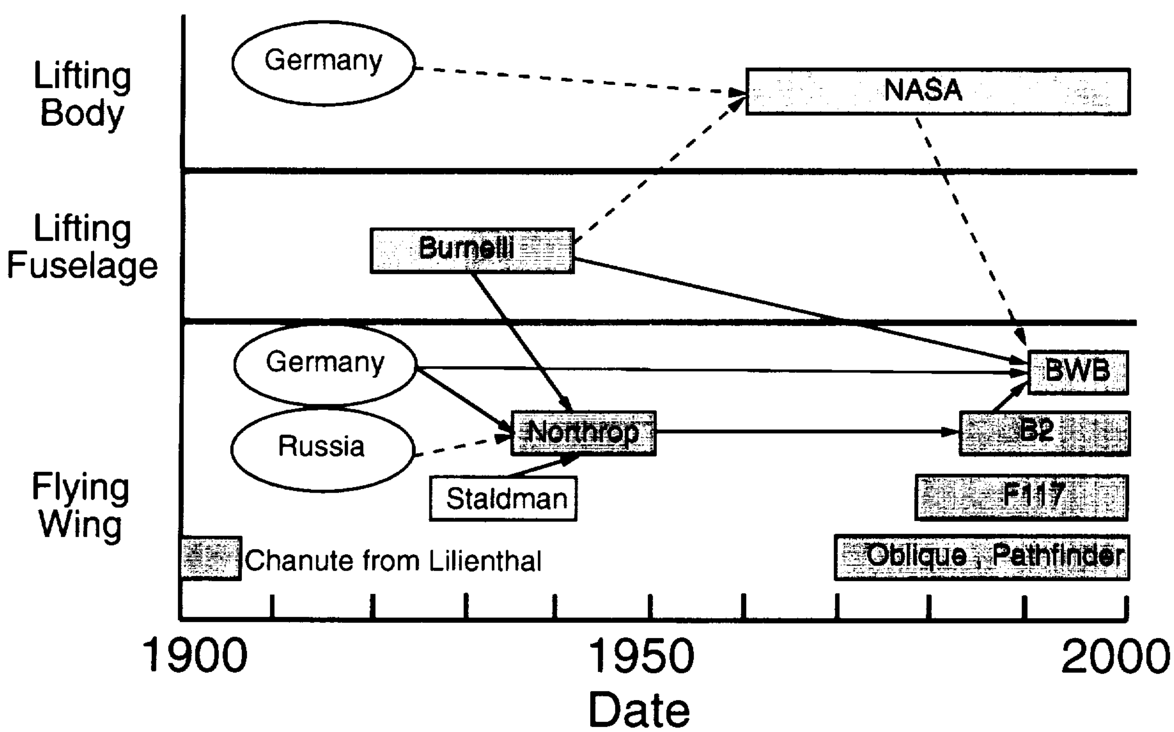


Figure 11. History of United States all-lifting-vehicle concepts.

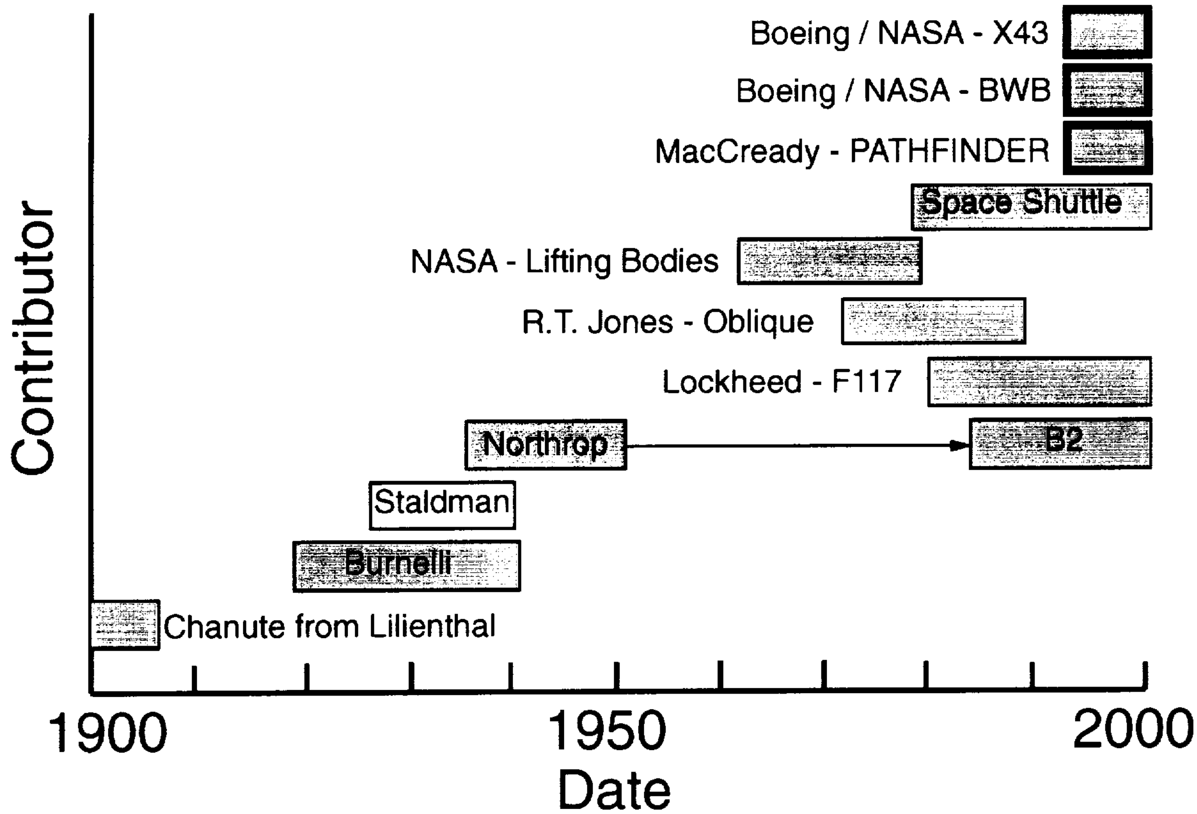


Figure 12. History of United States all-lifting-vehicle development.

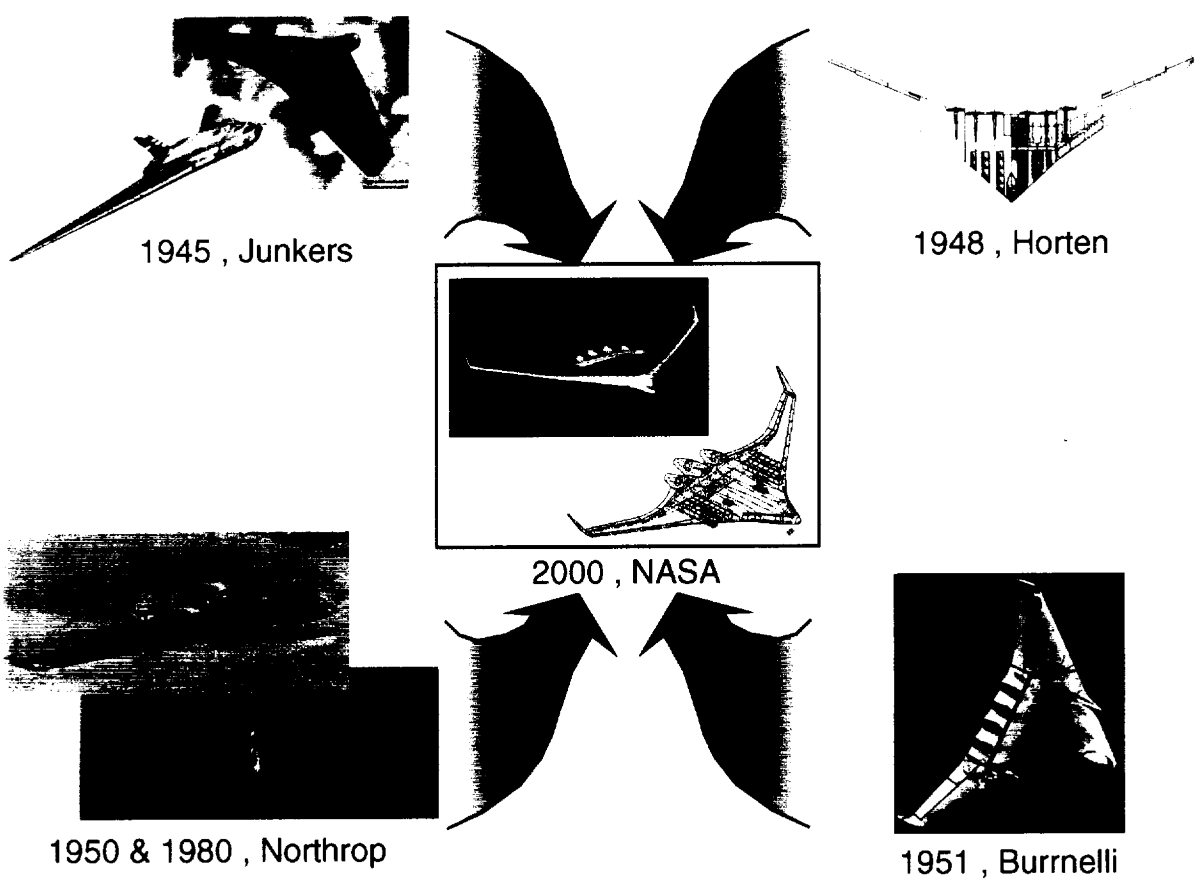
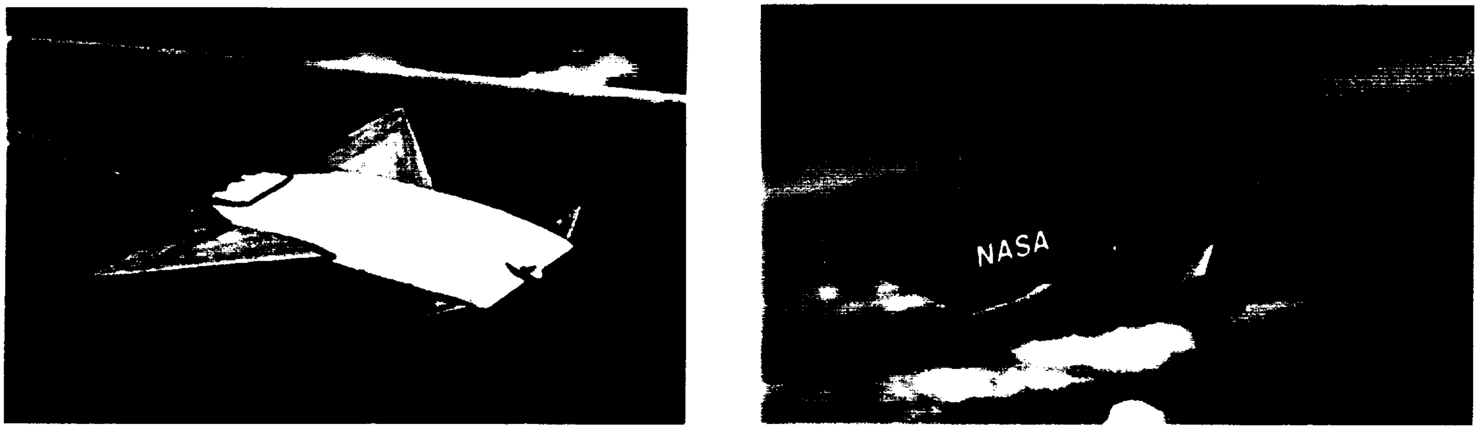


Figure 13. Historical comparison of flying wing transport designs.



1964 , Burnelli

2000 , NASA

Figure 14. Historical comparison of high speed transport designs.

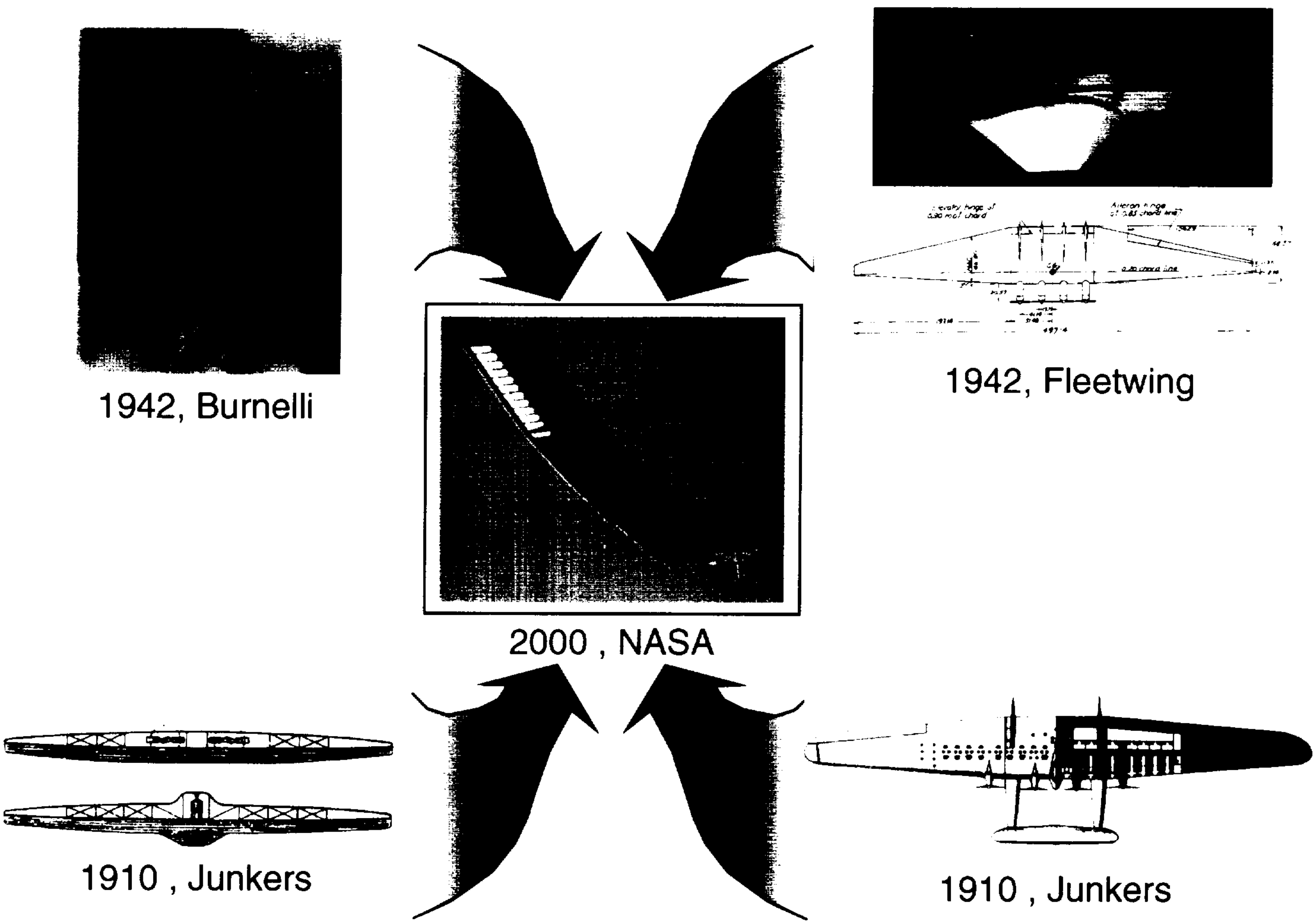


Figure 15. Historical comparison of low sweep vehicle designs.