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I am submitting herewith a thesis written by Klas Walace Ohman entitled "How They Flew: Modern Flight Test of Pioneering Wright Aircraft." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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Major Professor

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(Original signatures are on file with official student records.)

HOW THEY FLEW:
MODERN FLIGHT TEST OF PIONEERING WRIGHT AIRCRAFT

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Klas Walace Ohman
August 2004

DEDICATION

This thesis is dedicated to my parents

who inspired me with the love for flight,

my wonderful daughters, and

most of all, to my wife for her continued support.

ACKNOWLEDGEMENTS

This thesis would not have been possible without the incredible dedication and skill of Mr. Nick Engler and his staff at the Wright Brothers Aeroplane Company of Dayton, Ohio. His vast historical knowledge and exacting functional recreation of pioneering Wright aircraft were singularly responsible for the in depth understanding afforded our group of joint service and civilian pilots. Additionally, none of the gliders would have ever left the ground without the unparalleled help and support of the exceptional crew at Kitty Hawk Kites in Nags Head, North Carolina.

Further thanks are due the United States Navy, especially Carrier Air Wing Five, Strike Fighter Squadron 195 and Air Test and Evaluation Squadron 23 for allowing time off to complete these historic endeavors.

Throughout the project, the entire University of Tennessee Space Institute staff, especially Dr Richards, was always very responsive and willing to help at every turn. Their assistance was greatly appreciated.

ABSTRACT

The first controlled and sustained powered flight was arguably the single most important transformational world event of the 20th century. This accomplishment just over 100 years ago on the isolated, cold and windy Outer Banks of North Carolina was nothing short of miraculous. What enabled two bicycle mechanics from Dayton, Ohio to succeed where many others had tried and failed is also most incredible. However, unlike some other technical advancements, primarily either the Wrights or those interviewing them tell this story - with little independent verification. It is precisely for this reason that re-tracing the steps of these pioneers with the benefit of modern flight test methodology and without the bias of history is such an interesting undertaking.

A controlled and sustained powered flight consists quite simply of two parts. First, it must be powered and sustained – not gliding, but taking off and landing at the same elevation. Second, it must be controlled – the pilot must not just be along for the ride. The Wrights early on realized that gliding flight was possible and practical by studying the results of the earlier aviation pioneer, Otto Lilienthal. They further realized that his methods of control were sub-optimal. Eventually, the Wrights reasoned, sustained powered flight would be achievable if the forces of drag and weight could be overcome on an aircraft that was capable of being controlled. They knew so strongly that control was paramount to powered flight that it is this aspect of the problem which was the basis of their 1906 Patent # 821,393 [1]. Their advances were not without problems, however, only some of which were technical. There was at the time a very high-pressure race to see who would be the first to achieve the feat of sustained, powered flight.

They produced an historic equivalent of a modern technology demonstrator aircraft and documented the event photographically. Even with this evidence, it still took until 1944 for the United States to recognize their just place in aviation history.

Because of first flight competition, the remote location of their test site, the size of their test team, and several other factors, it can be postulated that perhaps some details of their flight test program and the exact physical properties of their aircraft might be not recorded exactly as they existed. These details could have been changed or omitted for proprietary reasons, or just not included because at the time it did not matter.

This thesis will document the daily flight test activities of the author and a team of multi-service test pilots as they review the historical record and put replicas of three pioneering Wright aircraft through tests that mimic those we feel the Wrights must have performed themselves. Through these tests several key issues will be brought to light as well as insight into the incredible skill, determination, scientific method and luck which ultimately allowed the brothers to achieve their goal one windy morning in December, 1903. Additionally, many facets of testing historic aircraft in an age of concern for risk management and safety along with parallels to modern flight test will be presented. Historical data will come from a number of sources, while actual flight test data will be from reports of trials conducted by the author (Navy test pilot), and both operational and test pilots from the United States Air Force and United States Army. These trials were conducted between 4 to 8 October 2002 in Jockey's Ridge State Park, North Carolina; 1 to 12 October 2003 in both Jockey's Ridge and Currituck County Airport in North Carolina; 13 and 14 December 2003 in Dayton, Ohio; and finally January 10, 2004 in Dayton, Ohio.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE AND ABBREVIATIONS

AOA	Angle of Attack
AOB	Angle of Bank
CG	Center of Gravity
deg	Degrees
FAA	Federal Aviation Administration
FCS	Flight Control System
HP	Horse Power
HQR	Handling Qualities Rating
Hz	Hertz (Cycles Per Second)
IAS	Indicated Airspeed
kts	Knots – Nautical Miles per Hour
kgs	Knots Ground Speed
lb	Pound
MAC	Mean Aerodynamic Chord
mph	Miles Per Hour
msl	Mean Sea Level
NASA	National Aeronautics and Space Administration
RWTED	Right Wing TED
RWTEU	Right Wing TEU
PIO	Pilot Induced Oscillation

ROTC	Reserve Officers Training Corps
TED	Trailing Edge (of control or wing) Down
TEL	Trailing Edge Left
TER	Trailing Edge Right
TEU	Trailing Edge Up
USN	United States Navy
USAF	United States Air Force
USA	United States Army
Vne	Never Exceed Airspeed
WBAC	Wright Brothers Aeroplane Company

CHAPTER 1

INTRODUCTION

OVERVIEW

The first controlled and sustained powered flight was arguably the single most important transformational world event of the 20th century. This accomplishment just over 100 years ago on the isolated, cold and windy Outer Banks of North Carolina was nothing short of miraculous. What enabled two bicycle mechanics from Dayton, Ohio to succeed where many others had tried and failed is also most incredible. However, unlike some other technical advancements, primarily either the Wrights or those interviewing them tell this story - with little independent verification. It is precisely for this reason that re-tracing the steps of these pioneers with the benefit of modern flight test methodology and without the bias of history is such an interesting undertaking.

STATEMENT OF THE PROBLEM

A controlled and sustained powered flight consists quite simply of two parts. First, it must be powered and sustained – not gliding, but taking off and landing at the same elevation. Second, it must be controlled – the pilot must not just be along for the ride. The Wrights early on realized that gliding flight was possible and practical by studying the results of the earlier aviation pioneer, Otto Lilienthal. They further realized that his methods of control were sub-optimal. Eventually, the Wrights reasoned, sustained powered flight would be achievable if the forces of drag and weight could be could be overcome on an aircraft that was capable of being controlled. They knew so strongly that control was paramount to powered flight that it is this aspect of the problem which was the basis of their 1906 Patent # 821,393 [1]. Their advances were not without problems, however, only some of which were technical. There was at the time a very high-pressure race to see who would be the first to achieve the feat of sustained, powered flight.

They produced an historic equivalent of a modern technology demonstrator aircraft and documented the event photographically. Even with this evidence, it still took until 1944 for the United States to recognize their just place in aviation history.

Because of competition in the race to fly first, the remote location of their test site, the size of their test team, and several other factors, it can be postulated that perhaps some details of their flight test program and the exact physical properties of their aircraft might be not recorded exactly as they existed. These details could have been changed or omitted for proprietary reasons, or just not included because at the time it did not matter.

OBJECTIVE OF THE STUDY

This thesis will document the daily flight test activities of the author and a team of multi-service test pilots as they review the historical record and put replicas of three pioneering Wright aircraft through tests that mimic those we feel the Wrights must have performed themselves. Through these tests several key issues will be brought to light as well as insight into the incredible skill, determination, scientific method and luck which ultimately allowed the brothers to achieve their goal one windy morning in December, 1903. Additionally, many facets of testing historic aircraft in an age of concern for risk management and safety along with parallels to modern flight test will be presented. Historical data will come from a number of sources, while actual flight test data will be from reports of trials conducted by the author (Navy test pilot), and both operational and test pilots from the United States Air Force (USAF) and United States Army (USA). These trials were conducted between 4 to 8 October 2002 in Jockey's Ridge State Park, North Carolina; 1 to 12 October 2003 in both Jockey's Ridge and Currituck County Airport in North Carolina; 13 and 14 December 2003 in Dayton, Ohio; and finally January 10, 2004 in Dayton, Ohio.

CHAPTER 2

BACKGROUND

PROJECT BACKGROUND

A number of years ago, Mr. Nick Engler, a master craftsman, published woodworker, and director of The Wright Brothers Aeroplane Company (WBAC) from Dayton, Ohio made the decision to devote his life to recreating and understanding the Wright's inventions. More importantly, his ultimate goal was teaching his findings to the youth of America in order to rekindle interest in aviations future by accurately describing its very beginnings. Rather than just present youth with the same story written in the history books, he endeavored to show how they achieved their goals with hands on exhibits and demonstrations. Lastly, since only the Wrights themselves documented most of their early experimentation, he chose to be an aviation archeologist vice historian and take nothing as absolute until he had re-created it himself. To that end, he has created accurate replicas of every Wright aircraft on its 100 year anniversary. These included: The 1899 Kite, the 1900, 1901, 1902 Gliders, and finally the 1903 Flyer. It should be noted that operating funding for the WBAC came primarily from the display and operation of these aircraft. This was considerably different than other project teams that either created 1903 replicas as hobbies, or were sponsored by very large public companies and organizations.

The author's involvement in this project started in late September 2002 after the decision was made by the USS Kitty Hawk (CV-67) Public Affairs Team to send a representative to the town of Kitty Hawk, North Carolina to renew ties with the namesake city during the festival of Return to Kitty Hawk. While plans were being made for the event, it was determined that the WBAC would welcome the participation of an experienced pilot with a diverse flight background in the planned 1902 replica flights that year. The only other qualifier was that the pilot had to weigh 145 $\pm$ 15 pounds. This ultimately secured the job for the author, being one of only a very few people in the ship's Air Wing with the appropriate qualifications *and* weight. After the initial 1902 events, the author and the other military pilots on the team were invited to stay on as advisors and pilots for the 1903 replica trials that were to take place the following year.

HISTORICAL BACKGROUND

Just over 100 years ago the Wright Brothers created what could arguably be seen as the single greatest invention of the 20th century. Their first interest in flight may well have come from a small toy called a bat, which was given to them by their father [2]. Their first serious study into the problem of manned flight came after reading of the exploits of the renowned Otto Lilienthal of Germany (figure 1). His book, *Birdflight as a Basis for Aviation,* detailed his great number of successful gliding flights using primarily weight shift as a means of aircraft control [3]. Lilienthal died in 1896 from an upset due to a gust that could not be overcome by this mechanically simple, early method of control. His design's relatively high stability with its horizontal and vertical tail aft of the main wings and the relatively low control power of weight shifting were more than likely the prime reasons the brothers chose the overall control scheme they later did [3].

1899 Kite

Their first aircraft to be controlled by wing warping was the small 1899 kite. It consisted of two control sticks which, when actuated opposite each other, would warp the wings either right or left.

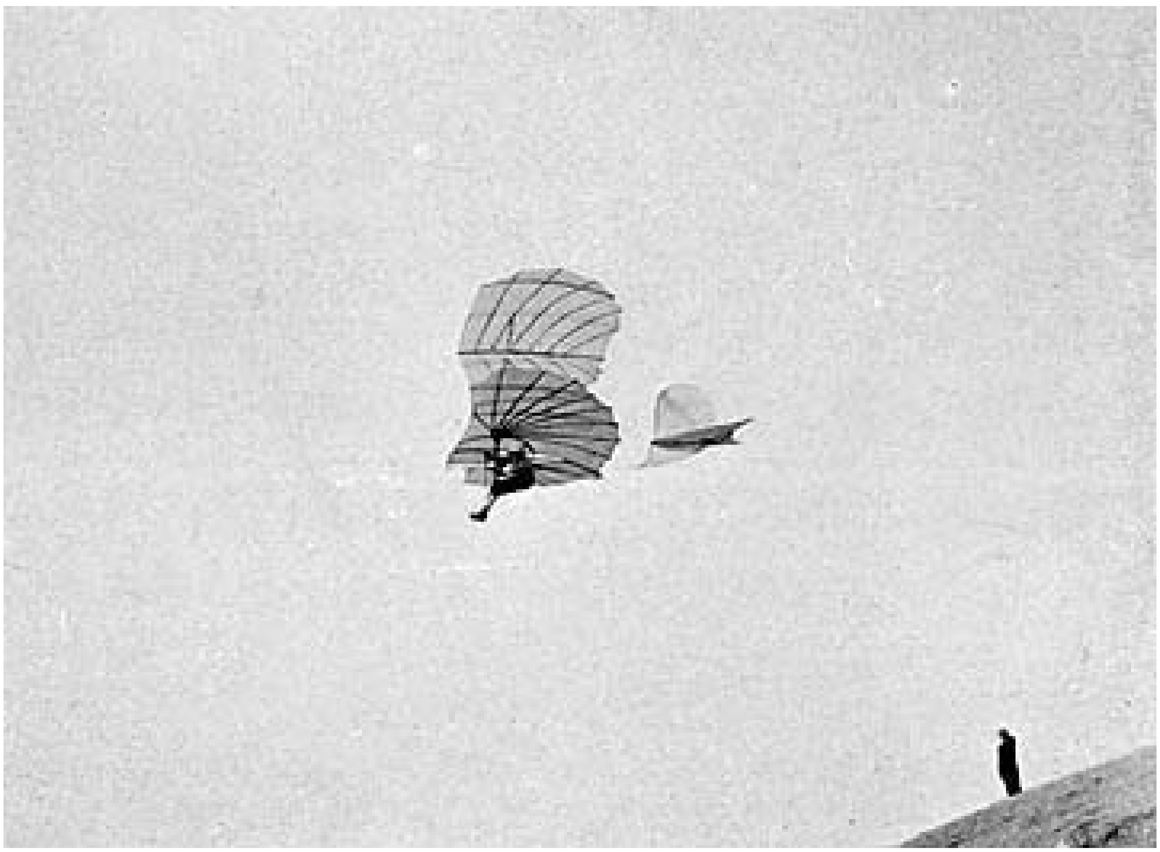

Figure 1
Otto Lilienthal In Flight

Source: Carol, Gray. (viewed 2004, April 12). *Otto Lilienthal* [WWW document]. URL http://www.flyingmachines.org/lilthl.html

This kite, along with their drawings (figure 2) would later play a crucial role in the Wright's patent litigation. Their copious notes, plus eyewitness testimony of those who had seen the kite fly ultimately convinced the courts that they had the first notion of warping two airfoils for lateral control of a flying machine. A more complete discussion of wing warping and overall control schemes of Wright aircraft is presented in appendices A, B and C.

1900 Glider

Their first attempt at a device large enough to carry a man was the 1900 Glider. Using Lilienthal's tables for lift (for elliptical wings) they fashioned a biplane glider with short wings and no vertical tail [4]. Experiments in the field with even moderate winds determined that the wing area of the 1900 was barely enough to keep aloft the weight of a small boy. It would however, through kiting, prove to them that the basic ideas they had for control of an aircraft would work. They retained wing warping and added a surface in front of the main wing that could be rotated up and down to satisfy the basic criteria for lateral and longitudinal control of an aircraft in flight (figure 3). Early on the brothers recognized that turning an aircraft would be much the same as turning a bicycle. The banking and resultant force exerted into the turn made the craft change its course, not skidding like the result of a ship's rudder being turned.

1901 Glider

The second attempt at gliding flight with their 1901 glider still utilized the Lilienthal lift tables with a much thicker, lower aspect ratio, but larger surface area wing (figure 4). The results were also not good for these trials. The aircraft sank excessively and was extremely difficult to control in pitch. It was at this time the brothers decided

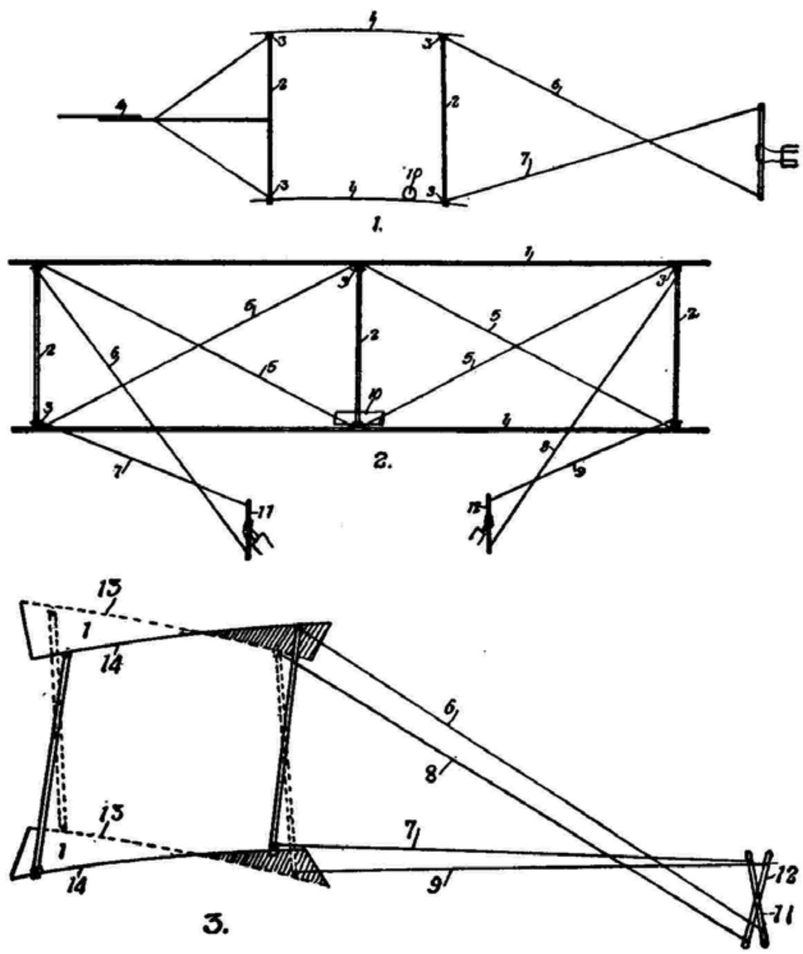

Figure 2
Engineering Drawing Of Wright 1899 Kite

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

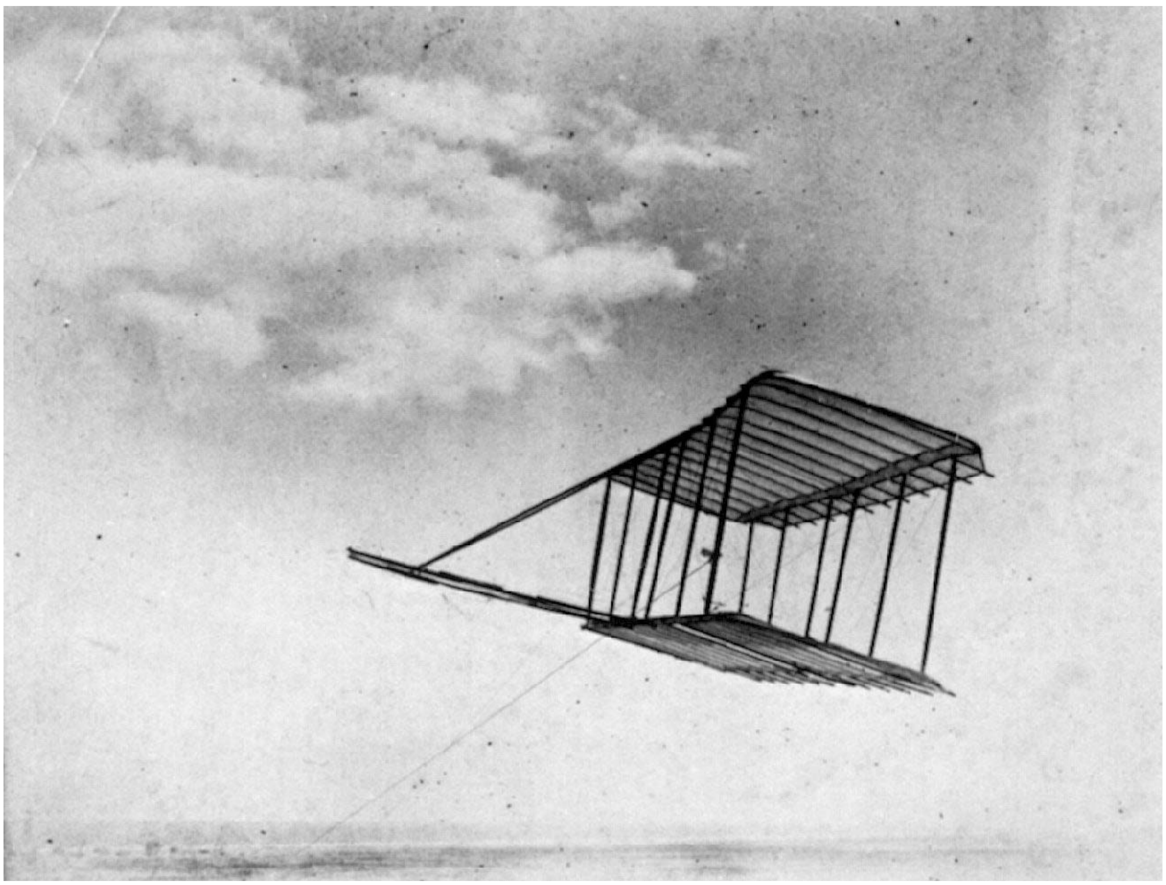

Figure 3
1900 Glider Being Kited

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

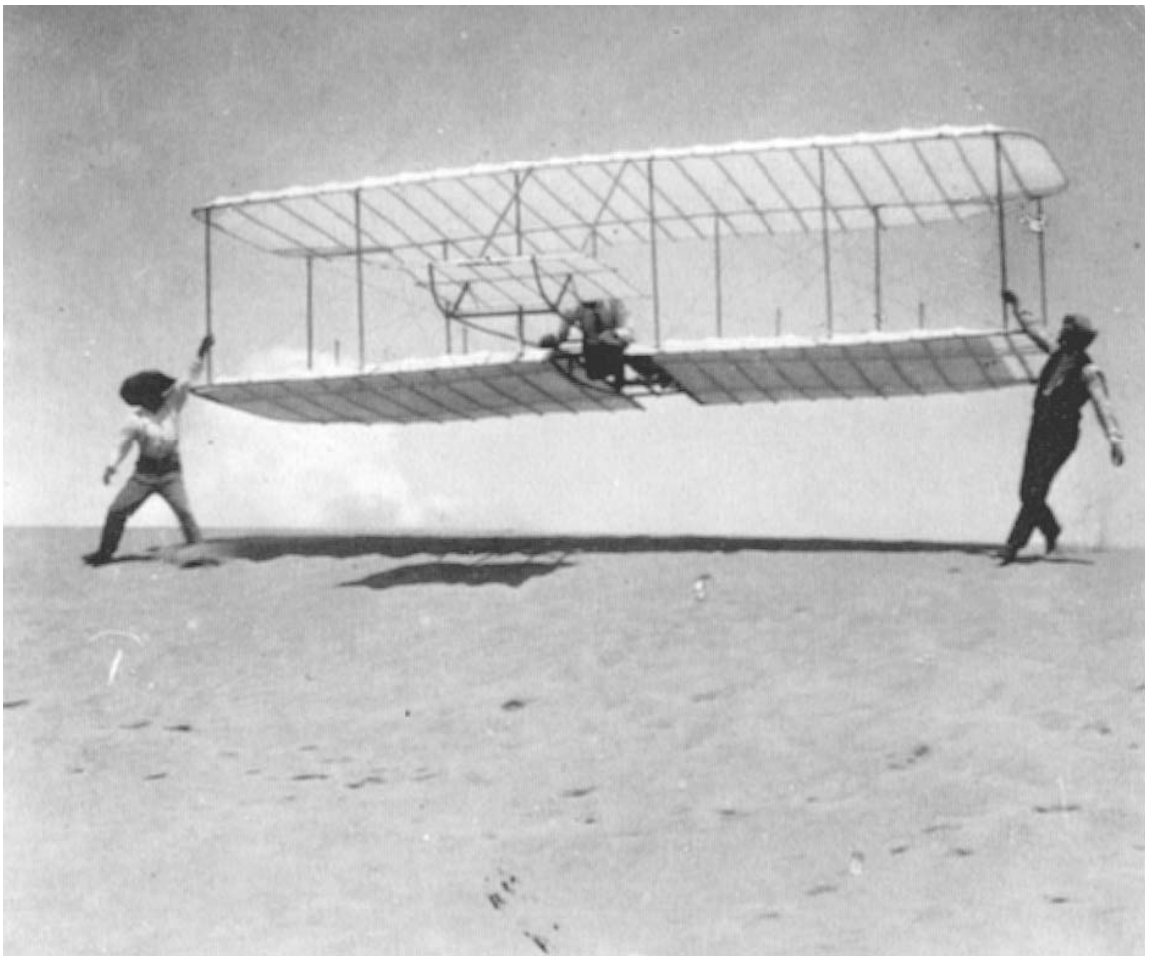

Figure 4
1901 Glider Being Launched

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

that the tables of the master Lilienthal must be in error and set off to create their own. The wind tunnel and device the brothers invented for determining lift and drag non-dimensionally of various airfoils could be a thesis in itself and will not be discussed in depth here. The airfoil that resulted from their scientific study was state of the art for the time, and along with some other factors ultimately allowed them to achieve their goal.

1902 Glider

After determining the optimum airfoil, aspect ratio, configuration and interplane spacing from their wind tunnel results, the brothers produced a very effective gliding machine in the 1902 Glider. Only one modification was required to the aircraft for the first goal of controlled flight. Early in the season they enjoyed very good glide distances as long as no turning or leveling of the wings were required. If this happened, they would either sideslip or spiral in and crash. They soon realized that some form of directional stabilization was required and fixed a non-movable vertical tail to the 1902. In straight and level flight the device had the desired effect, however, in a turn it seemed to exacerbate the spiraling (well digging) effect [5]. Finally it came to them that the rudder must be turned in the same direction as the wings to keep sideslip from building and spiraling (it seems they recognized adverse yaw, but not spiral stability). After some minor ratio adjustments, the new moveable rudder resulted in a true world aviation first: A fully controllable three-axis aircraft (figure 5). This was the basis of their 1906 patent, not the 1903 powered flyer [1]. The rest of the season they taught themselves to fly doing more than 1000 glides in the relative secrecy of the Outer Banks, primarily because by this time they were in a very close race with S. P. Langley for the distinction having the worlds first heavier-than-air controlled, sustained powered flight

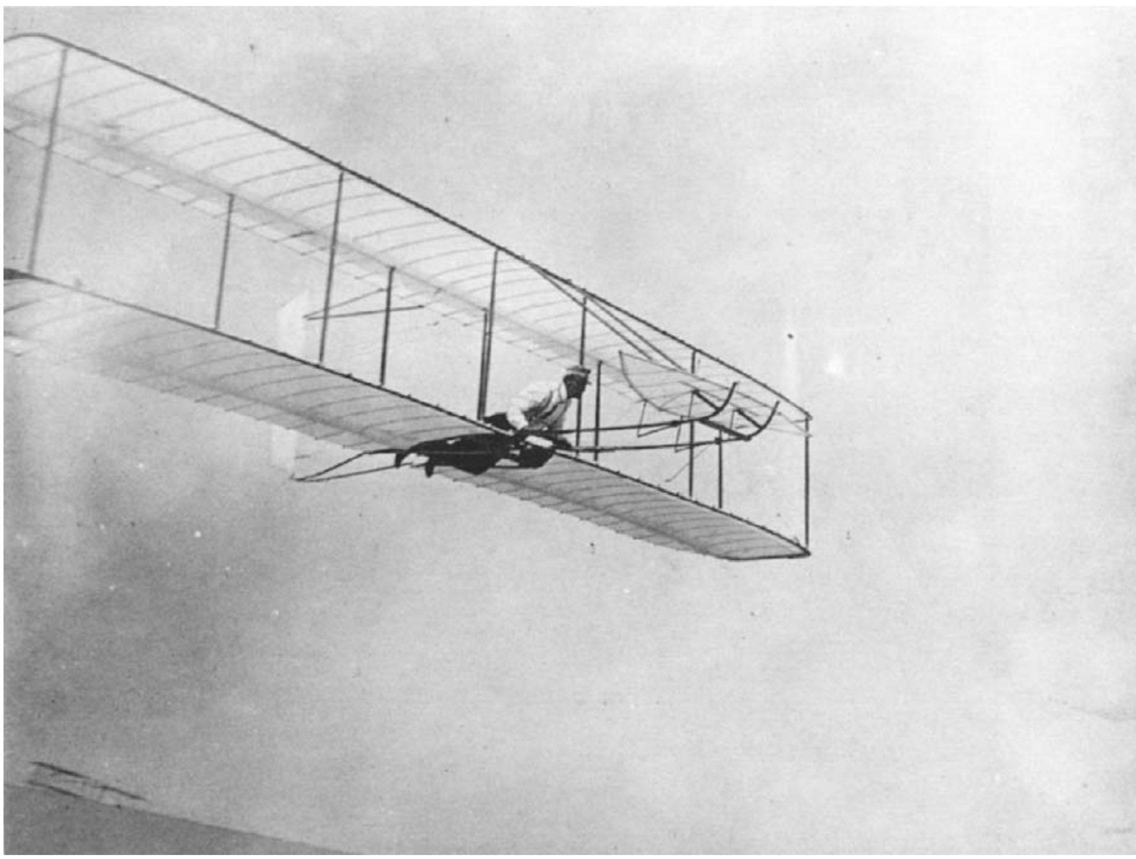

Figure 5
1902 Glider In Flight

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

1903 Wright Flyer

The 1903 Flyer was basically a scaled up version of the 1902 with some modifications to the lateral flight control system (FCS) and an engine. It kept the grossly unstable configuration of the 1902 while growing in weight significantly. No longer being able to be hand launched, they developed a rail and truck system from bicycle wheel hubs. For landing, skids were added. Unable to find a suitable engine from industry, they developed their own from specifications derived primarily from their wind tunnel and 1902 glider data. Their propeller design was miraculous for the time, with modern techniques only able to best their results by a couple of percent [6]. The drive system for the propellers was chosen by their mechanical experience with bicycle chain. Their friend and advisor, Octave Chanute remarked that never before had he seen a mechanical device engineered with such small margins (weight, drag, drive train losses, etc. to available power from the engine). As the final assembly neared at Kitty Hawk in 1903 these words from Mr. Chanute (whom they had continuously relied on for expert advice on their engineering calculations) caused the brothers to worry that their craft would never leave the ground [2]. On December 14th, 1903, however, the Flyer did leave the ground for a brief time, and then crashed approximately 60 feet away from the lift-off point. The Wrights did not credit this first day to a flight presumably due to the fact the aircraft was launched down hill on an almost 5 degree grade and landed lower than it took off. Of course, it could also have been because the cameraman (note shadow of photographer, figure 6) did not get a picture of the machine with air under its skids.

Three days later, on the 17th of December 1903, the aircraft lifted off into an approximate 25 miles per hour (mph) headwind from a level rail and flew approximately

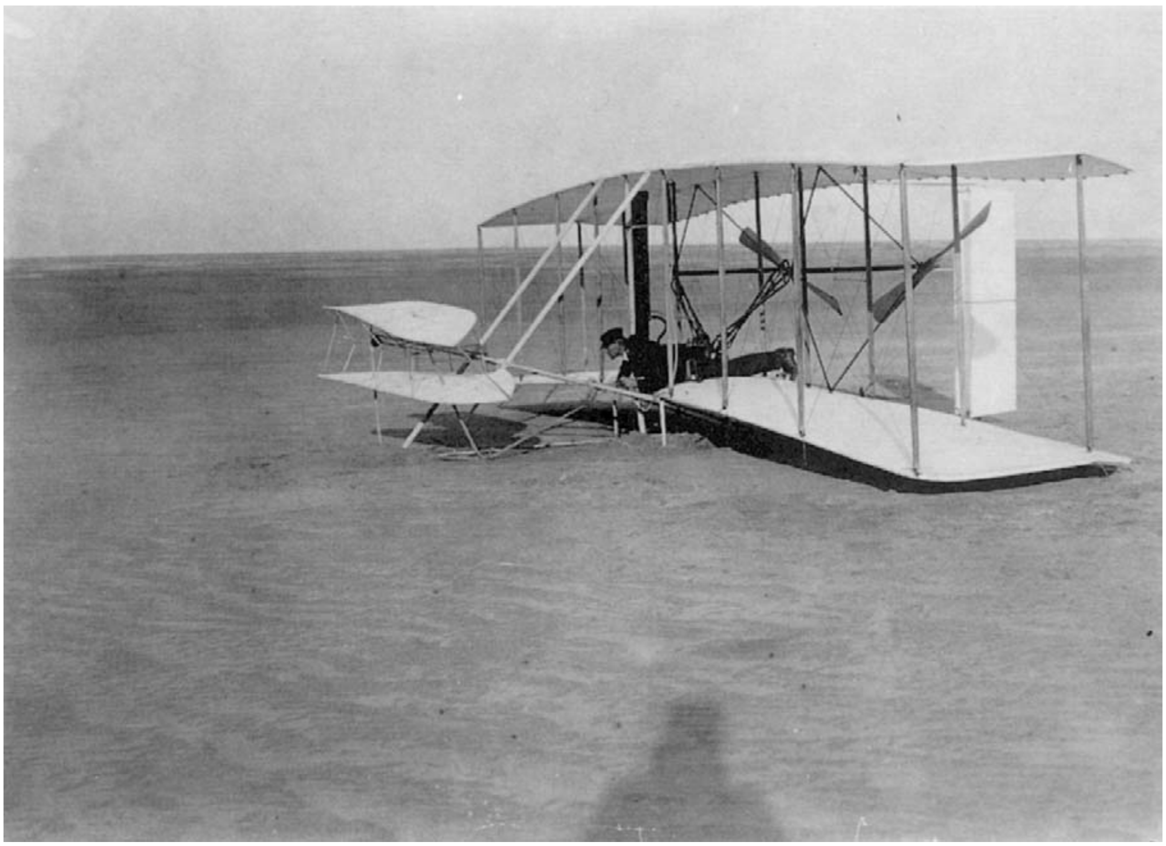

Figure 6
1903 First Flight 14th December

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 3* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos_3.htm .

100 feet (see figure 7 and figure D-4) [5]. Three more flights were made that day before the aircraft was returned to the vicinity of the hangar. Around then, a gust of wind flipped and virtually destroyed the machine. Most of the pieces were boxed up and returned to Dayton. The Wrights returned home after releasing the story to the hometown papers in Ohio (they did not want the story published in North Carolina first).

HISTORICAL ACCURACY

It should be mentioned that the figures for the flight distances are approximate except for the last (fourth) one. Appendix D contains several sample days from Orville's diary for reference. Even for the fourth flight, the brothers who are normally so very methodical in their reporting don't say how the distance was measured (tape, pacing off, survey, etc). Thus, any exact figures for distances, engine speeds or flight times should be taken with some skepticism. The diaries of the Wrights, which for the most part are the same as a modern flight test daily report, aren't that specific. So, if it wasn't recorded exactly at the time, it is hard to see how it could come to an exact figure many years later. Continuing along this reasoning, the plans for the 1903 flyer were made from a heavily restored static display that hung in the English Science Museum until 1946 [6]. Before the plans were made, the aircraft was first destroyed by winds in Kitty Hawk, stored in crates which were underwater during a flood in Dayton, opened three years later, and ultimately meticulously restored by Orville in 1916 – 13 years after initial construction. The 1903 was constructed from a rough arrangement sketch (figure 8) and drawings of individual ribs, etc. What all this ultimately means is that no one really knows the exact configuration of the Wright 1903 Flyer, and all else are just very highly educated guesses. Thus, to find exactly what they created, it would be necessary to re-create their steps.

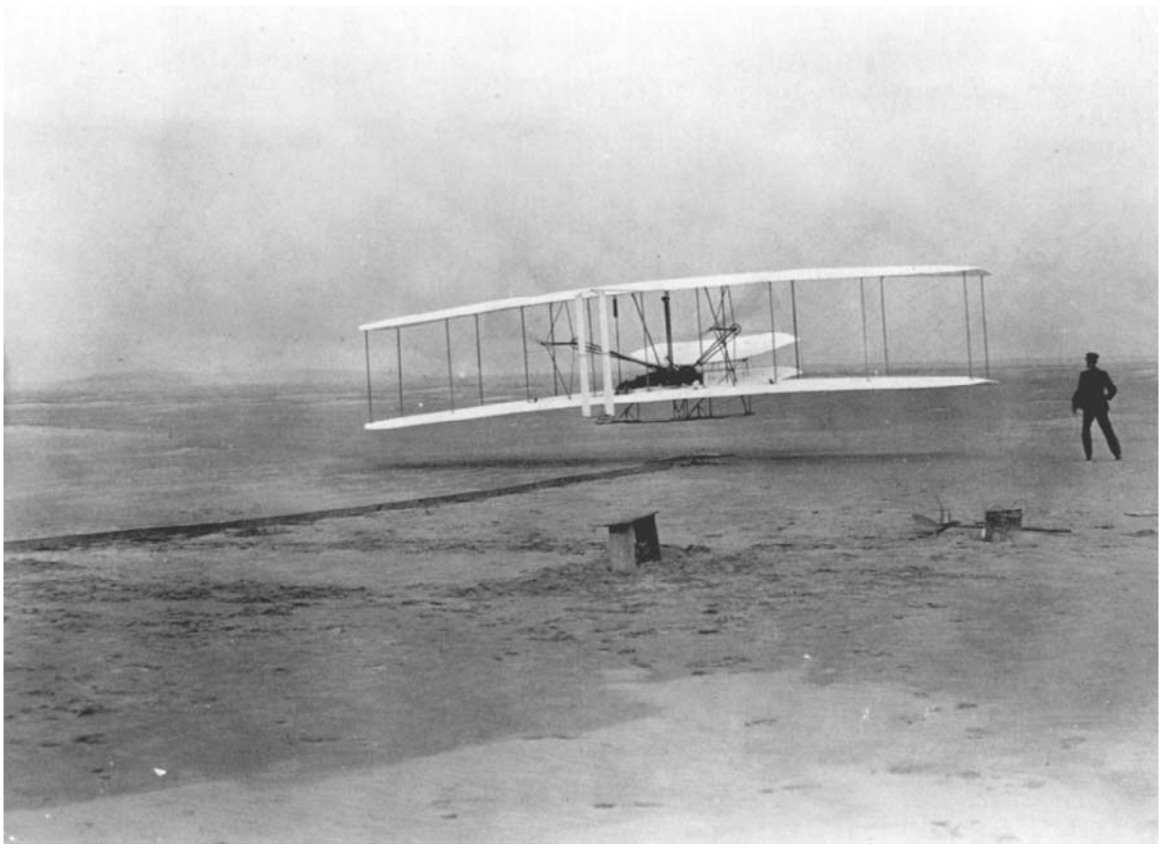

Figure 7
Flyer First Official Flight December 17th, 1903

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

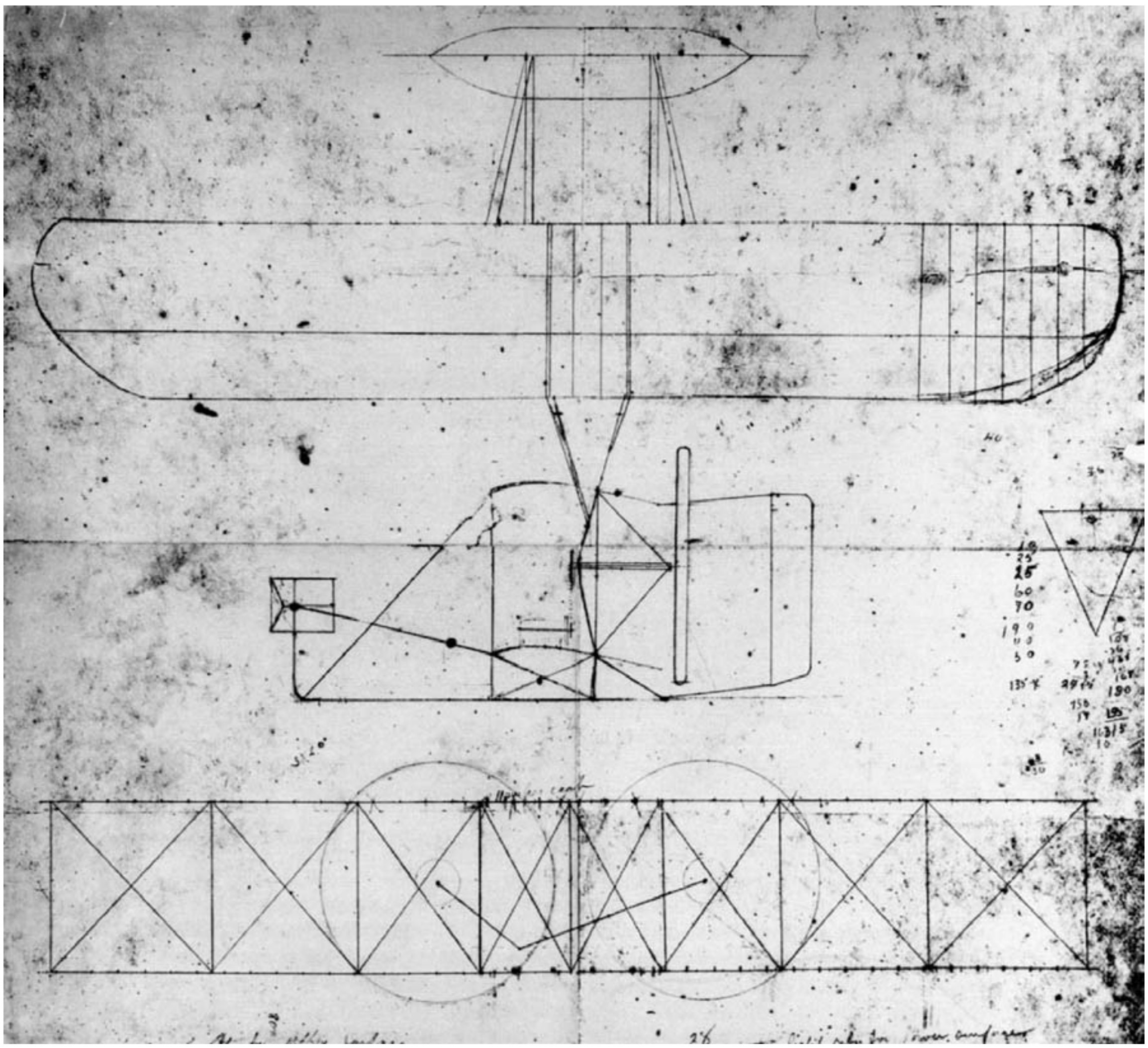

Figure 8
1903 Flyer "Plans"

Source: Engler, N. (viewed 2004, April 12). *Wright Photos 1* [WWW document]. URL http://www.first-to-fly.com/Information/Homework/wright_photos.htm .

CHAPTER 3

FLIGHT TRIALS

1902 GLIDER TRIALS AT JOCKEY'S RIDGE STATE PARK

Summary

A total of 25 flights by the report author and 95 flights total were accomplished during three days of flight test. A total of approximately 8 minutes and 18 seconds of flight time was accumulated by the author and 23:45 by the remainder of the test team. To assist in understanding their unique control mechanization a detailed technical description of the replica Wright 1902 is presented in appendix A.

Flight Dailies

First flight day, 4 October, 2002: 4 Flights.

Conditions: Winds were light from the west at 8-13 mph.

Configuration: The configuration was standard.

The Wrights had two methods of launch, one with the pilot standing in the center of the aircraft and running along with the wing runners and then climbing (jumping) in just as the aircraft started to fly. The second was with the pilot basically already in the flight position with the wing runners supporting both the weight of the aircraft and the pilot until sufficient airspeed was attained (figure 9).

Flight 1: For the first attempt the team decided to use the stand-up launch method. This resulted in an extremely short takeoff run with an early takeoff and ultimately a gentle stall. With the early lift off, the author was unable to "climb in" while the aircraft was flying away. The author also could not command enough nose down canard presumably due to the camber springs attached to the leading edge of the canard.

Figure 9
Wright 1902 Replica During Launch

Source: Engler, N. (Personal digital camera, photo taken October 2002).

Changes to Configuration: The glider's configuration was standard except the canard springs were removed.

Flight 2: The result of the second attempt was a very short flight. The author noted a lot of feed back in the pitch controller, which if released would go to full deflection either up or down. Longitudinal weight shift was not used for this flight.

Flight 3: This flight was of medium duration, long enough to allow some lateral inputs. The aircraft seemed very responsive in pitch, but extremely sluggish in roll. The fixed ratio yaw coordination seemed about right. The author did not detect any appreciable sideslip with the lateral inputs. Coordinated, experienced wing runners proved critical to any successful flights, as any runner induced yaw could not be overcome post launch.

Second flight day, 6 October, 2002: 13 Flights.

Conditions: The winds were brisk from the east at 13-18 mph.

Configuration: The glider's configuration was standard with no canard springs.

There were numerous flights today from the team. The flights were a mix of long and short duration. The morning flights were relatively short and very difficult to control in pitch. There was excessive slack (approx ½ inch) in the canard control cables, probably from successive ground impacts on previous test flights. As a result, the canard surface would *flutter* $\pm$ *4 inches* with the wings aligned at flight representative angles of attack (AOA). This uncommanded movement resulted in a great amount of feedback to the pitch controller. Pilot attempts to hold the canard surface still with the pitch controller were fruitless. Flights in this condition were possible, but all the team pilots were largely reacting to the aircraft vice controlling it. These flights were in the heart of the airspeed envelope, so the team did not use longitudinal weight shift for pitch control.

The afternoon flights were all of long duration, both in distance and time. They lasted approximately 10 seconds and covered approximately 250-280 feet over the ground.

Changes to Configuration: The glider's configuration was standard without canard springs, but with the addition of turnbuckles on both canard control cables.

Turnbuckles were added to the pitch control cables, which greatly reduced the tendency of the canard to flutter. There was still a large amount of feedback in the pitch controller. The canard could be held steady at flight representative AOAs with high forces and resting the outside palm section of the hands against the chain pulleys. Regardless of configuration, the canard itself would seek opposite the relative wind if allowed to deviate from center (i.e. the pitch controller itself was unstable).

The team noted that the airplane appeared to still have lift capability below an airspeed where the canard lost effectiveness (apparent canard stall). Discussions with hang gliding experts suggested that longer duration flights might be realized by using a combination of weight shift and canard control. This turned out to be exactly the case. With sufficient flying speed, the pitch controller alone could be used effectively with minute inputs (yielded approx 10 deg / sec pitch rate with an initial 2 lb pitch rotation). As airspeed decreased, or in response to gusts, a weight shift forward and aft of approximately 6 inches center of body mass could be required to maintain control. The pitch controller was essentially ineffective (in the nose up direction) below approximately 12 mph. Roll control was extremely sluggish at all airspeeds tested (note small change in differential wing incidence in figure 10). Large roll rates were not allowed to develop, however, the rate was estimated at 2 deg/sec with a full deflection right or left warp.

Figure 10
Wright 1902 Replica In Level Flight

Source: Engler, N. (Personal digital camera, photo taken October 2002).

A flight with pilot number one aboard resulted in ground impact in an approximate 10 mph sideslip. The impact caused slight damage to the glider that was repaired in about 2 hours. This event happened after a gust at slow speed placed the aircraft in a 15 degree right wing down attitude. The pilot shifted his weight left, but did not fully engage the hip cradle. This effectively leveled the wings, but did not zero the sideslip. It was apparent from this maneuver that the aircraft had very little capability to generate any sideforce (as can be surmised from a picture of the airplane, figure 10). It was also noted that there was a great deal of resistance in the left/right movement of the hip cradle with any vertical load on it. A metal strap was added under the wooden cradle bar to give smooth metal on metal contact which with light oiling provided for easy full deflection of the hip cradle regardless of vertical loading (figure 11).

Third flight day, 8 October, 2002: 8 Flights.

Conditions: The winds were strong from the east at 19-25 mph.

Configuration: The glider's configuration was standard with turnbuckles on the canard control cables and a metal strap on the bottom of the hip cradle slide mechanism.

Long flights were the order of the day with one exception due to a minor over-control of down canard on takeoff run. One flight resulted in a dynamic roll end over end after touchdown when the pitch controller was left briefly unattended by pilot number three. The aircraft completed three full rotations in pitch while mostly maintaining ground contact. Pilot three was basically unhurt and the aircraft was sufficiently repaired to fly again just 45 minutes later. Repairs to the aircraft were made in much the same way the Wright's would have done, with waxed binding string and wood glue. Modern tools like electric drills were used, however, to speed the repairs somewhat.

Figure 11
Wright 1902 Replica With Full Left Correction

Source: Engler, N. (Personal digital camera, photo taken October 2002).

Results

By the end of the third day the team's confidence in the capabilities of the aircraft was high. Although still a very difficult aircraft to fly in most aspects, it was beginning to be fun by this time. Towards the middle of the flight day, the author had enough spare capacity to assign basic Handling Qualities Ratings (HQRs) for elementary tasks [7].

The original mission of this glider was to provide a test bed. In other words, its mission was to test their theoretical data and enable the Wrights to teach themselves to fly. From an HQR standpoint, when this airplane was constructed there was not yet a mission for *any airplane*. Thus, there was no attempt made to assign the standard mission relation statement to any tasks listed.

Representative handling qualities ratings for selected 1902 tasks follow below:

Task: Maintain altitude
Tolerance: ± 2 feet.
Workload: Very high
Compensation: Required continuous pitch inputs at a rate of greater than 2 Hz to maintain desired height.
HQR: 8
Notes: Inattention for greater than 2 seconds would result in ground impact or stall. Altitude maintenance was also very important to the launch crew as they gathered speed. Too high an altitude would lift them off the ground and too low would result in a rather short flight and sore backs for the launchers.

Task: Maintain airspeed
Tolerance: Approximately ± 3 knots (a range from stall to Vne)
Workload: High
Compensation: Required continuous pitch inputs on the pitch controller and/or weight shifts at a rate of one per second.
HQR: 7
Notes: Inattention to attitude for greater than 2 seconds would exceed tolerances (airspeed range of the airplane as tested was 10 mph stall to 28 mph max speed)

Task: Maintain angle of bank (AOB)
Tolerance: Approximately ± 5 degrees
Workload: Extremely high

Compensation: Required difficult to time, near continuous inputs on the hip cradle from one half to full deflection opposite perceived minute angle of bank changes at a rate of one every 3 seconds to maintain level flight (see figure 11 for an example of simultaneous full roll and minor pitch inputs).
HQR: 8
Notes: Inattention to bank angle for greater than 2 seconds or gusts would result in uncontrollable sideslip and ground impact from AOB greater than 15 degrees.

Task: Maintain heading
Tolerance: approx $\pm$ 10 degrees
Workload: Extremely high
Compensation: Required coordinated hip cradle and pitch controller movement combined with weight shift as airspeed decreased at a rate of one input every second for the duration of the heading maintenance task.
HQR: 8
Notes: Most of the test teams flights did not attempt heading control at all, but just accepted heading and landed in that direction.

1902.5 GLIDER TRIALS AT JOCKEY'S RIDGE STATE PARK

Summary

A total of 8 flights by the report author and 25 flights total were accomplished during three days of flight test. A total of approximately one minute of flight time was accumulated by the author and two minutes by the remainder of the test team. A detailed description of the replica Wright 1902.5 glider is presented in appendix B.

Flight Dailies

First flight day, 3 October 2003: 2 Flights.

Conditions: The winds were light at 5 to 8 mph and the temperature was 70 degrees.

Configuration: The glider's configuration was standard.

Location: Most flights were made from the intermediate dunes to the west. These were chosen due to wind direction and experience gained from flying the 1902 the year prior.

Flight 1: The team originally started the day with flight attempts from the low dunes in low winds. Later operations were moved to less the desirable intermediate dunes with launches to the west into a landing area with many bumps and obstructions (grass clumps). The first flight was with pilot number two, who after a couple of short runs for 1902.5 familiarization, enjoyed a long flight of approximately 200 feet. The landing in the relatively flat grassy area, however, slightly damaged the front skid, which required approximately 30 minutes to repair.

Flights 2,3: The next flights from the same area were from pilot number six and the author. Both flights were very similar, with glide distances of approximately 175 to 220 feet. Although still unstable, the 1902.5 was qualitatively assessed to be much easier to control than the 1902. At the end of the day, it was planned to measure the aircraft CG accurately using a pipe and balance method.

Second flight day, 4 October 2003: Numerous Attempts.

Conditions: The winds were light at 4-7 mph and the temperature was 75 degrees.

Configuration: No changes were made since the last flights. The CG was accurately measured for all pilots by balancing the aircraft on a one inch diameter steel pipe. The average CG for all pilots was approximately 20 percent MAC.

Location: The flight test location for all attempts was from the very shallow low dunes (figure 12). These were chosen due to wind direction and a desire not to exceed pilot comfort for new pilot number seven. The team hoped to at least allow the newer pilots a chance to feel the controls of the 1902.5, even though from knowledge gained on the previous days flights and experience in the 1902 the year prior it was recognized that there was insufficient wind to support extended flights. Pilot number seven got approximately 5 human powered “tows” above the sand for 50 to 100 feet of nearly stalled, mushing flight.

Figure 12
Wright 1902.5 Replica Transported To Intermediate Dune

Source: Engler, N. (Personal digital camera, photo taken October 2003).

Third flight day, 5 Oct 2003: 12 Flights.

Conditions: The winds were 9 to 12 mph and the temperature was 65 degrees.

Configuration: No configuration changes were made since the last attempts.

Flights 1 and 2 were made by the author and pilot number six. Both flights were from the intermediate dunes to the east for winds and familiarity with the 1902 at that location. These flights were uneventful, and as on the first 1902.5 flight day, the aircraft handled predictably in all circumstances. Its glide performance was considerably worse than the 1902, and resulted in very short flights from the intermediate dunes. A proposition was made by the author to move the aircraft to the high dune to the east (90 feet above the park floor), given the predictability of the 1902.5 and a desire to further refine pilot technique prior to attempting flight in the 1903 flyer. This was met with skepticism by another member of the team who thought flights from the high dune were unduly risky. Following a test team meeting it was decided to first launch from part way up the high dune on an unlevel surface, and with satisfactory results proceed to the top of the dune.

Flight 3: The author's first flight from the high hill half way up point was uneventful. The launch was difficult for the launch crew, but rolling the airplane level after launch was not difficult. It required a ½ deflection input opposite the roll error followed by an immediate ¼ hip cradle deflection input to check the rate to zero. The flight was approximately 2 to 3 seconds in length, so no qualitative assessment was made for pitch characteristics other than they were still unstable, but more docile than the 1902.

Flight 4: Pilot number six's flight from the same location was also uneventful. Both pilot six and the author agreed that the aircraft was predictable enough to warrant extended flights from the high dune.

Configuration changes since last flight: A digital anemometer was added to the front canard frame for airspeed reference.

Flight 5: The first flight from the top of the high dune was made with the author flying. Following extensive briefings about abort procedures and minimum wind limits, the conditions were favorable for the first flight without direct ground reference for speed. Winds were 10 mph for this flight. After a very short launch run and release, the ground fell away and the author set the typical pitch attitude for cruise. This seemed to be around 24 mph. For the duration of the flight it was necessary to make small, continuous inputs in the pitch axis to maintain attitude approximately level. Unlike the 1902, there was little feedback from the canards, and they basically stayed where they were commanded. Much like the 1902, the adverse yaw from the wing warp and rudder mechanical interconnect were in exact harmony. As a result, no apparent adverse yaw was noticed during lateral inputs to maintain wings level flight. The flight covered approximately 200 feet over the ground and lasted approximately 9 seconds (figure 13).

Flight 6 was the first flight from the high dune for pilot number six. It was uneventful and followed the same profile as flight 5.

Flights 7, 8, 9, and 10 were uneventful and served only to increase flight time and experience for the author and pilot number six. Of note, it was found on flight 9 that 26 mph was a very comfortable cruising speed and the aircraft responded nicely to control inputs at that speed while maintaining a relatively good glide ratio. This was calculated to be approximately 4 to 1 vice the 6 to 1 found for the 1902.

Flight 11 with the author flying was the first attempt in either the 1902 or 1902.5 to initiate a turn with the purpose of attaining a new heading vice just maintaining wings

Figure 13
Wright 1902.5 Replica In Flight From High Dune

Source: Garrigus, D (Still from personal digital camera, photo taken October 2003).

level. After launch, the author accelerated to the best glide speed found on flight 9. Once established, a full deflection hip cradle input was made to the left for less than a second. An immediate opposite ½ deflection hip input was then required to check the resultant roll rate. It seemed that any angle of bank greater than approximately 5 degrees the aircraft wanted to rapidly keep going in that direction, so no angles of bank greater than 10 degrees were attained. Every input in the lateral axis seemed to result in pitch axis movement, but whether the lateral axis was the cause of this movement or if it was just a manifestation of the unstable longitudinal axis was undetermined. In either case, maintaining the cruise flight attitude required continual, small pitch inputs and immediate counter corrections throughout the duration of the flight. For all the flights, the flare was surprisingly easy, requiring only a well timed, smooth application of full back stick as the aircraft neared the sand. As the stick came back, the skids would drag, slow the airplane down, it would stall and the flight was complete.

Flight 12 with pilot number six aboard was flown with the intent of maintaining the same profile as flight 11. The flight went smoothly until the turn attempt when the pilot accidentally input a large pitch command while attempting to move the hip cradle. As he countered the resultant rapid pitch up, a large pilot induced oscillation (PIO) developed which seemed to be abated only as his airspeed decelerated to near stall. Pilot number six then quickly regained control of the pitch axis and landed without incident. This reinforced for the entire test team that flying an unstable, antiquated aircraft could never be taken lightly.

Results

Following the high dune launches, the test team's confidence in their future ability to control the 1903 replica was high due to the great successes enjoyed from the 1902.5 flights. A number of the problems with the 1902, such as poor control harmony and sluggish roll control, were corrected in the 1902.5. Pitch control was also much better, in part due to the increased friction of the dual canard control cable mechanism. With just a little friction, the canard did not try to "run away" when deflected as quickly as the 1902. The airplane's CG was moved considerably forward due to the extra weight for the dual canard and supports. All of these factors combined to make the airplane much more enjoyable in the pitch axis. Although the airplane was easier to fly than the 1902, it was still unstable in all three axes, as the sampling of handling qualities ratings demonstrate.

Representative handling qualities ratings for selected 1902.5 tasks follow below:

Task: Maintain airspeed.
Tolerance: Approximately ± 3 knots.
Workload: High.
Compensation: Required continuous pitch inputs on the pitch controller and/or weight shifts at a rate of one per second.
HQR: 5
Notes: Inattention to attitude for greater than 2 second would exceed tolerance (the airspeed range of the airplane as tested was approx 22 mph stall to 28 mph max speed).

Task: Capture angle of bank.
Tolerance: Approximately ± 5 degrees
Workload: High
Compensation: Required inputs on the hip cradle from one quarter to one half deflection opposite angle of bank changes for angles of bank greater than 5 degrees at a rate of one every 3 seconds to regain level flight. Angles of bank greater than 5 degrees required continual inputs to stop roll rate from accelerating
HQR: 6

WRIGHT 1903 TRIALS AT CURRITUCK COUNTY AIRPORT

Summary

A total of 27 simulated flights, rail runs and short hops by the report author and the test team were accomplished during five days of flight test. A total of approximately zero minutes and four seconds of unrestrained flight time was accumulated by the author and another four seconds in total by the remainder of the test team. A detailed technical description of the flight control mechanization and power plant set up of the replica Wright 1903 flyer is presented for reference in appendix C.

Location: The tests were conducted at Currituck County Airport, North Carolina on runway 04/22 (4700 feet in length) which was asphalt surfaced at 27 feet msl elevation. The grass beside the runway was used for all the rail launch tests. Initial assembly, power train break in and flight control rigging were performed in a nearby hangar.

Flight / Simulated Flight Dailies

First simulated flight day, 8 October 2003: 10 Sim Flights.

Conditions: The winds were light and variable from 040 degrees at 5 mph, the temperature was 75 degrees. Winds were measured from the launch rail or the center field windsock. Wind speeds and directions varied somewhat due to tall trees and other airfield obstructions

Configuration: The aircraft's configuration was a "standard" Wright 1903 with the following modifications.

- An initial 75 pounds of lead shot ballast was attached to the front cross member yielding a CG of approximately 19% MAC (reduced gradually to 25 lbs by end of program).

- A throttle and dual pitch control cables for the canard assembly were installed with tensioning turnbuckles on each set (figure 14).
- A 20 HP Briggs and Stratton V-Twin engine connected thru a clutchable 90 degree angle drive reduction gear box with approx 3-1 ratio to the chain drive was installed in place of the four cylinder Wright model. An historic Wright gear reduction of 2.87 to 1 at the propeller followed the 90 degree drive.
- The wing surfaces were coated with paraffin-xylene mix.
- Additional bracing was added to the landing skids along with strengthened ribs surrounding the pilot area (figure 15).
- The rear takeoff dolly was initially mounted directly below the rear spar under the downward support for the main landing skid.

Ground test vehicle: A Ford F250 with a gimbal mechanism mounted in the bed that was positioned 8 feet 6 inches above the ground was used for the poor man's wind tunnel tests. A hydraulic ram in the support base raised the top part of the platform and allowed approximately 7 degrees of pitch/roll freedom per inch of upward extension (figure 16).

Configuration changes: The aircraft was partially disassembled, raised with a front end loader, securely attached to the top of the pivot platform, and then reassembled.

First simulated run. With pilot number four aboard, the team conducted a run without the propellers engaged to check structural integrity of the pivot and aircraft. Test speeds of 20, 24 and 32 mph were attained into the wind on runway 04. The aircraft exhibited apparent canard effectiveness as low as 22 mph. The tufts attached by the author to the lower canard surface to aid in determination of this number were not useable. In this configuration, full nose down canard was required to maintain a level attitude.

Figure 14
Wright 1903 Replica Pitch Control / Throttle Detail

Source: Ohman, K. (Personal digital camera, photo taken December 2003).

Figure 15
Wright 1903 Replica Landing Skid / Engine Detail

Source: Ohman, K. (Personal digital camera, photo taken December 2003).

Figure 16
Wright 1903 Replica Mounted Atop Gimbal

Source: Sheridan, J. (Personal digital camera, photo taken October 2003).

With power applied during the runs, neutral canard maintained approximately a level attitude. Simulated flights reached a maximum indicated airspeed (IAS) of 32 mph with a maximum hydraulic vertical ram extension (raised the aircraft pivot platform) of 1.5 inches for approximately 12 degrees of freedom in roll and pitch.

Fourth simulated run. With pilot number two aboard, the first trip was made with zero ram extension for familiarization, then at 0.5 inches, all at 24 mph IAS (figure 17).

Fifth simulated run. The run was completed with 1.5 inches of ram extension and initially flown with excessive nose down. This yielded only a roll trainer run (the nose of the aircraft never came off the forward limit stop).

Sixth simulated run. This run was flown at 1.5 inches extension with coaching from the chase crew for greater aft stick application and was without incident.

Seventh simulated run. Pilot number five's first trip was non eventful.

Eighth simulated run. On this trip the airspeed was incremented to 35 mph, which resulted in roll control forces that were excessive to the point that they could only be barely managed. Pitch control was reported as *extremely* sensitive at this speed. The run was ultimately aborted due to failed roll control lower warping wires. The wires were 1/16 inch stainless steel aviation grade cables.

Ninth simulated run. The author's first trip on the sting was started at 24 mph and 0.5 inches of ram extension. No significant issues were noted. The aircraft weathervaned approximately into the relative wind, as it did on previous runs.

Tenth simulated run. The author's second trip was at 31 mph with an initial 1.5 inches of ram extension. After setting the level flight attitude, the aircraft responded sluggishly in roll, and slightly unpredictably in pitch with continual $\pm$ 5 degree pitch bobbles.

Figure 17
Wright 1903 Replica Pilots View And Instruments

Source: Ohman, K. (Personal digital camera, photo taken December 2003).

Maintaining level flight ± 3 degrees was very difficult, requiring near continuous well shaped ± ¼ deflection inputs opposite the direction of the random pitch excursions that were well timed and continually reduced in magnitude.

On the same run it seemed that the rudder/aileron interconnect was not as well coordinated on the 1903 as on the 1902.5. This could be due to the increased inertia of the truck mounting attachment. Yaw disturbances generally seemed to seek the relative wind, yet initially when lateral controls were input, the nose would wander ± 5 degrees around the relative wind until the lateral input was removed.

At the end of the second run a slightly higher than level flight attitude was set and the pivot table ram extended *greater than 5 inches*. This allowed a very large freedom of movement in roll and pitch, which was for the most part controllable. The run had to be aborted due to a faulty rudder framing cable (the builder had inadvertently used the static display rudder - which had electrical connectors on the cable ends instead of NicoPress fittings). This allowed the rudder assembly to fail out of column. The rudder failure was followed by an immediate pitch down and left yaw. Simultaneously a second failure occurred on the left lower warping cable.

Initial Simulated Flight Results

The team found following data (with engines on): *Stall speed* could not be exactly defined, however it likely will be determined by the canard which maintains effectiveness down to approx *24 mph IAS*. *Vne (never exceed speed)* was bounded by excessive roll control forces at approx *35 mph IAS*. Speed at which lift was apparently greater than weight was found to be *31 mph IAS* (speed at which the gimbal table was lifted up by the airplane).

First unrestrained test day, 9 October 2003: 1 Rail Test.

Conditions: The winds were steady from 050-060 at 8-14 mph and the temperature was 70 degrees.

Configuration changes since last flight:

- Linear potentiometers were added for delta warp, canard, and rudder.
- The flight control cabling was changed from 1/16 to 3/32 inch on the wing warp controls, the lateral axis was rigged with both trailing edge tips 2.5 inches lower than the leading edge of the same tip (greater positive incidence on the outer wing panels than the inner). The engine kill switch was slightly modified with a longer attachment to ensure ease of engine shutoff.

Single test event. The author completed a taxi acceleration run to 60' of rail travel from a standing start. Winds at start of run were from 050 degrees at 5 mph. After a push to start from the wing walkers, the aircraft accelerated to 18 mph indicated with the engine at full power. There appeared to be a significant amount of friction on the front bearing. Bystanders reported the front bearing was frozen and not turning. After cutting the engine at 60 feet of rail remaining, the aircraft decelerated to a stop with 30 feet of rail remaining. No adverse trends were noted. The engine, props and flight controls looked good on post flight inspection.

First flight day, 10 October, 2003: 6 Flight Attempts.

Conditions: The winds were from 045-050 degrees at 10-12 mph and the temperature was 75 degrees with light mist to rain.

Configuration changes from the last flight: Three roller bearings for nose and main truck bike hubs were replaced.

Attempts one and two: Two trips down the rail with the author at controls were made during periods of light rain. On the first run 21 mph was the maximum speed, and the second was 19 mph as indicated on open top type anemometer. Poor acceleration at best was noted, and the aircraft seemed to cease acceleration on both attempts at approximately 20 mph IAS. At the end of rail approximately ¾ to full aft canard was applied with zero effect. Conditions during both attempts were with 75 pounds ballast on the nose and the main takeoff dolly at the under rear wing spar location.

After some time the fabric covering material became wet, which required the team to relieve excessive force in the outboard wing ribs at the wingtip by cutting the trailing edge "fingers" on the wingtip.

The team broke to assess the results mid-day. An error was discovered in the positioning of the main takeoff dolly (the main dolly assembly can only be positioned under a vertical strut on the landing skids, anywhere else would break the skid). Originally, the builder told the test team that the dolly belonged under the vertical support which attached to the rear spar. This was approximately 3 feet aft of the empty Wright historic CG. There was discussion amongst the test team to move the dolly forward, closer to the CG, but the builder initially dismissed this idea. The thought then from the test team was that if the Wrights had taken off with the dolly there (which was the original briefing), then we should be able to also.

Configuration changes from last flight: The takeoff dolly was moved to a mid-cg position with strut provided by the Wright design. During down time later that evening, the team found positive proof of the December 17, 1903 dolly location via historical photos from the builder and experimentation.

Conditions: The winds were from 010-030 degrees at 10-12 mph with gusts to 17 mph. The temperature was 80 degrees with light mist around the airfield.

Third attempt. Pilot number five was able to rotate the aircraft with the new dolly position and made a short hop of approximately 5-10 feet. Pilot number five's technique for rotation was an abrupt input of full aft stick followed immediately by neutral controls.

Fourth attempt. The author's flight attempt had a similar result as pilot number five. The author's rotation technique resulted in a slightly low pitch attitude at liftoff which produced a 5-10 foot level hop off the rail. No lateral control issues were noted on this very short run. The initial acceleration after the wing runners released seemed somewhat better now with the dry aircraft. However, even with the perceived greater acceleration, the aircraft was still only getting to approximately 21 mph indicated by the end of the rail. Its acceleration seemed to stop at approximately this point on all runs.

Fifth attempt. Pilot number three's attempt started with the left wing down all the way until the end of the rail. At the end of rail the pilot slightly over-rotated which resulted in a slight left turn after short airborne distance of 10-15 feet. The engine backfired and quit just prior to "landing".

Sixth attempt. Pilot number three's second trip was wings level with a similar airborne distance. The engine again seemed to fail just after rotation. It appeared the aircraft was not getting enough thrust to attain or sustain flying speed. A data review after the flight confirmed that the longitudinal acceleration became negative immediately after rotation, but prior to the engine failure. Post flight analysis also indicated that the engine quitting after rotation was possibly due to the positioning and operative sense of the engine kill switch that was modified for rail acceleration tests the day prior.

Second flight day, 11 October, 2003: 1 Flight Attempt.

Conditions: The winds were from 000 to 040 degrees at 8-15 mph, becoming 17-19 mph later in the afternoon. The temperature was 70-75 degrees.

Configuration changes from last flight:

- The kill switch was moved to the opposite side of the center inter-plane strut.
- The canard rig was adjusted to correct a warping that was discovered after a day in the rain.
- The lateral controls were re-rigged to a zero washout condition. Again, the team reviewed historical photographs and confirmed that the 1903 Wright aircraft was rigged in this manner, with the same resting angle of incidence for all wing panels (outer and inner). The initial rig had been to the builder's specification with 2.5 inches lower on the rear spar than front i.e., the outer panels had greater angle of incidence than inner.

Pilots number four, three and seven went in the morning to Jockeys ridge to practice in the Wright 1902.5 due to fantastic wind conditions there.

First Attempt. The author waited in position for an attempted run with the propeller clutch engaged after discussions with test team. This was designed to warm up the engine for maximum horsepower and be ready for any gusts that might come. After approximately three minutes of run time, lots of smoke coming from under the engine signaled a drive belt failure. This failure required the entire engine assembly to be removed and effectively ended the days test options due to a 4-5 hour repair time required for the replacement drive belts. The test team strongly recommended switching to an all gear and chain system.

Third flight day, 12 October, 2003: 9 Flight Attempts.

Conditions: The winds were 280 to 300 degrees at 8 to 10 mph, becoming 0-5 later in the afternoon. The temperature was 80 degrees.

Configuration changes from last flight.

- The destroyed drive belts were replaced with thicker models. Initially the belts were non-clutchable. After five minutes of break-in run time, even the thicker belts had to be used with the clutch tightened all the way down.
- A 250 pound-force by 140 foot stroke catapult system (created by 4 lengths of ½ inch shock cord) attached to the landing skids via a hang-glider tow release system mounted on the pitch control yoke (it occupied the throttle location seen in figure 14) was added. The aircraft then required a holdback system, which was made from two rope loops and a screwdriver.
- All operations were moved to the approach end of runway 04 in a grassy area with 360 degree takeoff direction availability.

First Attempt. Pilot number three first completed a checkout of the new bungie (shock cord) launch system. The first configuration tried was with both bungies at 90 degrees angles to end of track. This system did not create enough force for long enough, so the team moved to a combined bungie system about one wingspan apart at approximately 140 feet from the end of the tracks. This resulted in a system whose force varied from approx 20 lbs at the end of the rails to 250 lbs at 120 feet down rail (at the starting point).

Second attempt. Pilot three made a trip down the rail with the right wing down for the entire run and landed right wing down at end of tracks. The wing runners were instructed to continue to run as long as possible.

Third attempt. Pilot number three's second trip resulted in an approximate 10 foot flight with bungie assist into a 10 mph headwind. The end result was a nice "hop" with a slight nose pitch-up and gentle landing.

Configuration changes: The nose ballast was reduced to 25 lbs (CG now 28 %MAC).

Fourth attempt. Pilot number four fell immediately off the end of the launch rail during an attempt into a 10 mph right to left 90 degree cross-wind. The team then moved the launch rail 90 degrees to the right, which took about 45 minutes of labor with 4 men.

Fifth attempt. Pilot number five made a run with just a bungy assist and no motor power to check out the 25 lb nose ballast configuration. At the end of the run, the right wing runner (the author) slowed to quickly and imparted a yawing moment on the aircraft. The result was another flange failure of the dolly bike hubs due to excessive lateral loads. Primarily due to a lack of spare parts, two hours were required to fix the problem.

Sixth attempt. Pilot number five made a short hop off the end of the rail into a 5 mph left to right crosswind.

Seventh attempt. Pilot number five fell immediately off the rail after an attempted run with a 5 mph quartering tail-wind from left to right. Again, a damaged rear truck due to sideloads (flange failure) was the result. Moved the launch rail 90 degrees to the left, which again took approximately 35 minutes with 5 men.

This was the third failure of the bicycle hub truck/dolly system. Apparently, modern bicycle hubs are pressed together vice being milled from solid stock, as would have been the 1903 hubs the brothers used. This construction method was not sufficiently robust to handle the loads imparted by the 1903 with pilot aboard.

Eighth attempt. The author made a 20 foot “flight” into very light 2 mph winds. The initial acceleration of the vehicle was nice, with airspeed (and groundspeed) rapidly rising to that greater than the wing runners could keep up. At bungie release, and just prior to the last rail, airspeed was noted at 24 mph (just 6 mph shy of where sustained flight was historically possible). The rear truck of takeoff dolly was damaged as the dolly left the rail (*flange broken again – fourth failure*). The aircraft was very controllable in the lateral axis, and responsive to roll inputs. The pitch axis responded to the very ginger aft canard input and set the takeoff attitude with little overshoot (this was more than likely due to the very low airspeed off the rail). After securing the engine, the “flight” was measured by noting the distance from the end of the rail to the first gouges in the earth made by the landing skids.

Ninth attempt. Pilot number seven made a 5 foot hop off the rail after the rear takeoff dolly dislodged prior to the end of the rail run. Due to sunset and pilot operational schedules, this effectively signaled the last effort of the October trip.

Results

These many rail attempts were frustrating, but beneficial in that many members of the test team were able to experience the requirements for maintaining wings level and the initial pitch axis open loop rotation procedure, which would be critical for future attempts. The long duration runs aboard the gimbal allowed much more time to actually explore the operational envelope of the aircraft and fly it in a safe, restrained manner for more than just a few seconds. Additionally, the gimbal allowed the team to determine some critical flight numbers for the 1903.

Some representative handling qualities for 1903 gimbal tasks follow on the next page:

Task: Capture pitch attitude following takeoff
Tolerance: approx ± 5 degrees
Workload: Very high
Compensation: Required a very well timed and shaped initial pitch input followed by a very difficult to time and proportional input opposite the accelerating pitch attitude to stop the rotation.
HQR: 8

Task: Maintain angle of bank during rail run
Tolerance: approx ± 5 degrees
Workload: Very high
Compensation: Required difficult to time, near continuous inputs on the hip cradle from one half to full deflection opposite perceived minute angle of bank changes at a rate of one every 2 seconds to maintain level flight.
HQR: 7
Notes: Inattention to the bank angle for greater than 2 seconds would result in wingtip ground impact and subsequent loss of bank control.

WRIGHT 1903 TRIALS AT DAYTON, OHIO

Summary

A total of 4 short flights and rail runs by the report author and the test team were accomplished during two days of flight test. A total of approximately zero minutes and seven seconds of unrestrained flight time was accumulated by the author and five seconds by the remainder of the test team.

Location: The tests were conducted in a large field off the approach end of Runway 24L at Dayton International Airport, Ohio. Elevation of the field was 1009 feet msl.

Flight Dailies

First flight day, 12 December, 2003: 1 Flight Attempt.

Conditions: The winds were from 050-060 degrees at 5 to 13 mph, and the temperature was 25 degrees.

Configuration changes since last flight:

- A single 25 lb weight on forward strut for the most aft CG was deemed safe.

- A 25 hp Briggs vertical shaft engine replaced the 20 hp model.
- The clutchable drive system was removed. The belts were replaced with thicker models (the cogged belt system was backordered) .
- A throttle system was added to the pitch axis controller. The operative sense was pull for increased power and release for idle power (railroad dead man's throttle type set-up).

First attempt. With the author at the controls, the initial flight was similar to the previous "Wright Slider" hops of approximately 20 feet, but roll and pitch control felt good (figure 18). At release, the pilot sensed a comparatively very rapid initial acceleration of the aircraft. The wing runners were left behind after only a few seconds. Density altitude had definitely made a huge difference!

Second flight day, 13 December, 2003: 2 Flights.

Conditions: The winds were 050-060 at 10 to 15 mph and the temperature was 21 degrees with some light snow.

Configuration changes since last flight: There were no changes in configuration.

First flight. The first trip was with pilot number four aboard and launched with no nose ballast. A good initial acceleration occurred into a 14 mph head wind. The aircraft appeared steady laterally while traveling down the rail. The rotation maneuver was approximately ¾ to full aft canard as the aircraft approached the last rail. At this point, the aircraft over-rotated initially and rapidly left the launch rail. An immediate 10-15 degree nose up attitude resulted in a rapid loss of airspeed. Quick application of full nose-down canard with coordinated hip control to counter the left wing drop resulted in final ground impact in stalled condition at approximately a 10 deg nose up attitude. It is

Figure 18
First Unassisted 1903 Replica Hop

Source: Engler, Nick. (Personal digital camera, photo taken December 2003).

notable that there are numerous left wing drops visible in historic and modern 1903 pictures taken immediately following rotation.

Second flight. The author launched with 25 lbs of nose ballast into 13 mph winds. The initial acceleration was very quick for this model aircraft. Approximately 30 mph was attained as the aircraft approached the last rail. Initially during the run, lateral control was over-exaggerated for familiarization, and approximately 2/3 down the launch rail, lateral control was relaxed to concentrate on the upcoming pitch task. As the open-loop rotation maneuver was initiated, the horizon was completely obscured by the "Venetian blind" effect of the biplane canard. Simultaneously the left wing had already begun to lower slightly. As the lateral axis came back into the pilots scan, first ½ , then full right hip cradle was applied opposite the left roll. By this time the aircraft had traveled approximately 60 feet from the launch rail. At this point, unknown to the pilot, the left wingtip had contacted the ground and rendered the lateral controls unusable. The pilot perceived this as binding controls laterally and flew the skids slowly to the ground, ending the flight at approximately 120 feet from the end of the track (figure 19).

Results

Although short, these first true, successful flights of the WBAC's replica 1903 Flyer did allow for some post flight assignment of HQRs for discussion. It also confirmed the extremely small margins the Wrights had worked with and the great importance of density altitude, wind and gross weight in successful Wright Flyer attempts.

Handling qualities for some selected replica Wright 1903 Flyer flight tasks follow below:

Task: Maintain angle of bank
Tolerance: approx $\pm$ 5 degrees
Workload: Extremely high

Figure 19
Wright 1903 Replica Second Flight

Source: Favorite, MJ. (Personal digital camera, photo taken December 2003).

Compensation: Required difficult to time, near continuous inputs on the hip cradle from one half to full deflection opposite perceived minute angle of bank changes at a rate of one every second to maintain level flight.
HQR: 9
Notes: Inattention to bank angle for greater than 2 seconds or gusts would result in wingtip contact and subsequent loss of lateral control and eventual ground impact.

Task: Maintain altitude
Tolerance: $\pm$ 2 feet.
Workload: Very high
Compensation: Required continuous pitch inputs at a rate of 2 cycles per second or more to maintain desired height.
HQR: 8
Notes: Inattention to the pitch axis for more than 1 second resulted in ground impact or stall.

CHAPTER 4

CONCLUSIONS

GLIDER FLIGHTS 2002

Mr. Engler of the Wright Aeroplane Company built an extremely well crafted, precise and accurate replica of the 1902 Wright Glider. The design and construction resulted in an incredibly rugged flying machine that could withstand a fantastic amount of punishment.

Historically, this was the aircraft with which the Wrights taught themselves to fly [8]. It was basically a 4/5th scale model of the 1903 with a slightly different lateral and longitudinal flight control system. The aircraft was, as advertised, unstable in all three axes.

The Wrights had to have some method of tensioning pitch controller cables. Modern day flights with loose cables resulted in an aircraft that was basically uncontrollable. The particular method of tensioning is unknown, but it is the opinion of the test team that the Wrights could not have achieved the numbers of flights, distances or times they recorded with slack in their control cables.

The Wrights were an athletic, determined bunch. Their journals report some days with upwards of 50 or more flights a day with only a team of three. This would have really exhausted all concerned with the operation. For the test team, 30 flights each day *with* a day off in-between *and* a team of 4 to rotate through launch duty was extremely fatiguing. Continual (even though slow speed, with nominal flares to landing) impacts to the upper thigh by the hip cradle resulted in 4 by 6 inch bruising on the quadriceps.

Additionally, our present day test team was graced with the knowledge that the 1902 Glider was capable of controlled flight. The Wrights did not have this luxury. They had no way of knowing whether their failures were a result of their design, their flying abilities, the conditions, or all the above.

Once sideslip was allowed to build, there was no way to recover at the altitudes flown. There was no lateral resistance in the aircraft, save the very minimal form drag from the pilot.

Control harmony was atrocious between the lateral and longitudinal axes, as minute changes in the pitch controller would result in pitch rates of approximately 10 degrees per second, whereas full deflection of roll controller gave only a maximum of approximately 2 degrees per second. As long as sideslip was *not* allowed to develop, the balance of the coordinated rolling surface to rudder interconnect was very nice, and the airplane would stay in trim.

GLIDER FLIGHTS 2003

It has been said that the brothers were desirous of completing a 1902.5 replica for themselves prior to flying their 1903, but ran short of time to complete the aircraft [6]. The 1902.5 was in all ways an exact 4/5 scale model of the 1903 Flyer with the exception of an engine, drive train, and propellers. After flying the aircraft, especially from the high dune, the team felt well prepared to handle the flying qualities of the 1903. However, during interviews with Mr. Ken Kellet the year prior, he had stated that the 1902 flew much, much *better* than the 1903 [9]. Since the 1902.5 flew much better than the 1902, the team considered that it might have been good the Wrights did not complete their 1902.5. They might have gone into their 1903 attempts feeling that the aircraft would be as easy to fly as the 1902.5, which could likely have been disastrous.

POWERED ATTEMPTS CURRITUCK NORTH CAROLINA

The test team eventually had all the pieces in place for a successful, long duration flight. The pilots were trained and confident of the equipment on the 1902 modified and the truck mounted 1903. The engine was producing most of the horsepower it was capable of. The takeoff dolly was in the correct position, and the wing incidence was correct. The higher density altitude was somewhat mitigated by the catapult launch system. The problem, in the end, was really a shortage of time. On the last day, had the winds been greater than 15 mph, the aircraft *would* have flown with the lightweight pilots. That being so, the team ended up with a very similar issue to that which plagued the Wrights when they tried to fly their machine in Ohio during the summer of 1904 for the first time – density altitude. There was just not enough power available to allow the airplane to attain or sustain flight. Additionally, the replica 1903 under test was a bit overweight due to some safety and other modifications (increased structure under the pilot, stronger landing skids, turnbuckles for adjusting the flying and landing wires, the NASA instrumentation package, and probably the biggest contributor – the ballast added forward to move the CG to a more controllable point). There was just not enough power in the engine and propeller system to accelerate the aircraft or sustain flying speed without natural wind.

POWERED FLIGHTS DAYTON OHIO

With the addition of a larger motor, greatly decreased density altitude and a nominal amount of wind, the test team finally had all the requirements necessary to allow controlled, powered flight. In Dayton, the team also had the benefit of a better transportation system for the aircraft, which reduced the time required to move the machine from the hangar to the flying area. The tremendous difference in performance was immediately noticed on the first attempt at flight. In fact, even with very low winds, the acceleration after the wing runners let the airplane start moving forward felt much like it did when the bungy catapult system had been used in Currituck. The last element the team needed was wind, and that was satisfied on the 13th of December with two short flights into a 12 mph wind.

PROJECT

Overall, this flight test program was incredibly rewarding and similar to programs of today. There were schedule slides, delayed inspection approvals, political/press pressures, and lots of learning about the aircraft. This must have been very similar to what the brothers went through in their time (with the biggest differences being that it was not yet known if flight was even possible and they did all the work mainly by themselves). The one thing the Wrights had that the test team did not have was a small amount of time to wait for the best conditions. Because the builder had to use the airplane as a static display for his income, the time to test the 1903 was very compressed. This was further complicated by the very high press interest in the company, the machine and the pilots. Combined with schedule delays from the builder, FAA inspections, and down time required for repairs after each attempt, aircraft availability was severely limited for repeated flights. Further compounding these problems was the desire of the builder to have a large number of pilots on the team. This did not allow much experience to be gained by any one pilot due to the universal desire for everyone to get a chance at flying history. It did, however, provide a vast knowledge base of flight test and general flight experience with numerous excellent contributions from every member of the seven person pilot group.

Flight Test Methodology

Numerous factors combined to determine the order of tests and configuration of the replica 1903. The tests were conducted with the idea of build up in mind. Testing started on the restrained gimbal prior to free flight and with a forward center of gravity similar to the predictable 1902.5 before a historic CG. This was done for three reasons, the first of which was the desire to lower the risk to the people flying the aircraft while still preserving maximum authenticity. The second was to preserve the aircraft for the company, and third was to allow maximum participation by every pilot on the flight test team.

Reasoning For Success

Although harder to control, the team found the transition from the 1902 to the 1903 a natural one. Without this commonality between the airframes, they likely would have not had the skill set required to control the 1903. It is the author's belief that even with the vast flight and test experience of pilots on the team that flight of the replica 1903 would have been impossible without the 1902 flight time the prior year.

The team found the stubbornness and scientific method of the Wrights likely paid large dividends in their bid for flight. The Wrights were first to treat the aircraft propeller as a rotating wing versus a screw, as nautical engineers of the time did [6]. They were very reluctant to change from something they knew and lose their database of flight test knowledge. Even though there might have been a better way to design a part or configuration with better flying qualities, they stuck with what they knew. As a result, their figures for total drag and net thrust were very accurate, and more importantly calculated with very little overhead. They calculated the airplane would cruise at approximately 25 mph. Thus they designed their propellers to be at their maximum efficiency at that speed. What the brothers did not know was the density altitude at Kitty Hawk on December 17, 1903 was approximately negative 3400 feet, nor what effect it had on both their engine and propeller efficiencies and thrust. The initial acceleration after release in the Dayton flights versus the paltry performance in Currituck dramatically demonstrated this to the author and the test team.

Flight Characteristics

From the many runs with the 1903 replica mounted on its gimbal, the team found that at speeds faster than 35 mph, the airplane was basically uncontrollable in pitch, and required forces that broke the control cables in roll at the same speed. From this, the team was confident in setting a Vne of 35 mph for the aircraft. The first attempt at flight from the Wrights on December 14, 1903 resulted in a violent pitch up to a stall and subsequent crash. This flight was launched in relatively low winds on a 4 degree 58 minute down slope, and described by Orville as rapidly accelerating faster than he could keep up with the machine [5]. It could be possible that the Wrights found the same Vne speed the team did, but as was their style, figured that it was their control of the machine that was at fault.

Through the many attempts in Currituck, it was found that at speeds less than 28 mph, the airplane was unable to sustain level flight and would decelerate immediately after rotation due to insufficient thrust. Thus, the entire speed envelope of the airplane was only 6 mph. Airspeed too slow or too fast, temperature too warm, or not enough wind would yield failure each and every time.

The team found that the weight imbalance and additional 4 inches of extra wing on the right side of the aircraft had much greater effect than the Wrights had intended. Originally designed as a simple solution to offset the greater weight of the engine with extra wing area (the right wing is 4 inches longer than the left), it had little effect in the zero lift attitude encountered traveling down the launch rail. Thus, a significant amount of left hip cradle had to be maintained until just prior to rotation. At rotation, both left and right wings would go to a positive lift attitude and the extra wing area would go from being ineffective to overly effective and a rapid left roll would develop. This can seen in figure 7 and in numerous pictures of 1903 replicas immediately following rotation.

Historical Gaps

It can be proven from the picture in figure 6 that on December 14, 1903, the Wrights had only one control cable (on the starboard side) on their longitudinal system. The pictures from the 17th of December are either from the wrong angle or to fuzzy to tell whether or not they added another cable as the test team did with the replica 1903. With only one cable, the weight or aerodynamic load of the canards must be overcome by first transferring the load through torsion of a five foot long piece of 1 ½ by 1 ¼ inch ash wood to a bellcrank, then to a single thin control cable (figure 14). In experiments without the port side cable in place, the test team found that approximately three inches of movement of the control stick occurred prior to the canard deflecting at all. This, combined with the extremely unstable nature of the 1903 makes it possible that the Wrights added a control cable to the port side of their flyer on either the 15th or 16th of

December while they made other repairs to the airplane. Other teams who created and flew Wright 1903 replicas with historic centers of gravity and only one starboard side control cable had a number of spectacular crashes after losses of control in pitch.

It could be argued that the plans for the Wright 1903 do not show this extra cable, and the 1903 on display in the Smithsonian does not have it either. This could be due to a number of factors, but there are a number of notable issues concerning the Smithsonian 1903 and the Wright 1903 plans: The original 1903 was partially destroyed by wind following the December 17th flight; the pieces were boxed, shipped to Dayton and remained in a shed where they were completely covered by water in the Dayton flood of 1913; the boxes were unpacked and a "painstakingly" correct reproduction was made by Orville in 1916 (13 years after the flight); it was recovered and shipped to England in 1926 after the Wrights became disgruntled with the Smithsonian; plans were drawn from this model in 1948; then the flyer was returned to the United States[6]. The original "plans" the brothers used in 1903 are shown in figure 8. Additionally, review of the Wright diaries (their version of a flight test daily) has shown that distances for the 1903 flights are mostly approximate, even though many "exact" numbers are published today. See figure D-4, Appendix D.

OVERALL

In conclusion, through replication of Wright flight test, the opportunity of a lifetime was realized to gain a unique insight into just how they flew. Given this experience, it was surely only a divine combination of determination, scientific method, stubbornness, skill, athleticism and just plain luck that allowed them to succeed and change the world forever one cold December morning a century ago.

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APPENDICIES

APPENDIX A

Detailed Technical Description of the 1902 Replica Wright Glider

Single place, man launched, canard elevator biplane glider constructed of wood, muslin fabric, string bindings, metal attachment fittings, and wires. The aircraft was assembled following copies of original plans by The WBAC of Dayton, Ohio, USA. The pilot was situated in the center of the aircraft and supported his weight in a push-up type position with his hands on the pitch control bar and feet on the aft lower wing spar.

Flight Control Description:

Pitch control was affected by a combination of a rotary bar linked to the all flying canard elevator and forward/aft weight shift. Connection from bar to canard was cable and chain to bellcranks which drove the trailing edge of the canard. Optional springs were attached to the canard leading edge. With the springs attached, movement of the belcranks caused both angular rotation of the canard and canard camber change as well. Sense was twist forward for down (TEU) canard, twist back (TED) for up.

Roll control was mechanized to warp top and bottom wings together. A movable "hip" cradle was actuated by the outer thighs and was connected to cables and chains to pull on opposite corners of each wing (upper leading edge to lower trailing edge and vice versa), thus creating warping throughout the entire wing structure. Sense was slide right for right roll (RWTEU) and left for left roll (RWTED).

Yaw control was directly linked to roll and was not adjustable by the pilot. Hip cradle slide right resulted in right rudder (TER) and slide left gave left rudder (TEL).

Modifications to the test aircraft:

The fabric covering was coated with paraffin/xylene mixture for decreased permeability. Tensioners (turnbuckles) were added to canard elevator linkage. Padding was added to hip cradle and crossbar. A metal strap was added under the hip cradle to allow the cradle to slide more smoothly. Duct tape was added to exposed screws/nuts/bolts in the vicinity of the pilot station for safety.

Table A-1
Wright 1902 Glider Physical Characteristics

Weight as tested:	Approx 120 lbs
Pilot weights:	105-210 lbs (report author 145 lbs)
Aircraft gross weight:	225 to 330 lbs
Span:	32 feet, 1 inch
Length:	17 feet, 0 inches
Height:	6 feet, 3 ½ inches

APPENDIX B

Detailed Technical Description of the 1902.5 Replica Wright Glider

Single place, man launched, biplane canard elevator biplane glider constructed of wood, muslin fabric, string bindings, metal attachment fittings, and wires. The aircraft was assembled following copies of original plans by The WBAC of Dayton, Ohio, USA. The pilot was situated in the center of the aircraft and supported his weight in a push-up type position with one hand on the stick and the other on the connecting control bar with his feet on the aft lower wing spar.

Flight Control Description:

Pitch control was affected by a stick attached to a rotary bar linked to the all flying canard elevator and to a lesser extent, forward/aft weight shift. Connection from bar to canard was by dual cable and chain to bellcranks which drove a rotary bar. The rotary motion of this bar was transferred by unequal-length parallelogram connectors to the leading and trailing edge of the canard. This arrangement caused not only angular rotation of the canard surfaces, but camber changes as well, similar to the 1902. See figure B-1 next page. The sense was stick forward for pitch down (TEU) canard, twist back (TED) for up.

Differences between 1902 and 1902.5 lateral FCS are detailed in figure B-2. The primary difference between the two lateral systems was an abandonment of the pinched box design common to the 1900,01 and 02 gliders. That system caused the top and bottom wings to slide forward and backwards relative to each other while the front and back of the wings were held in a fixed geometry, which in turn caused the entire top and bottom airfoils to bend (warp). This effect can be most easily seen by looking down the open end of a cardboard box and pulling two of the diagonally opposite corners together. The 1902.5 system on the other hand, fixed the top and bottom airfoil geometry in all planes out to the last wing panel. On this last panel, the leading edge geometry was fixed while the trailing edges were free to move up and down together in concert. The trailing edges were pulled up or down by opposing cables attached to the last rib of the wing prior to the wingtip and the top or bottom of the last inter-plane strut of the fixed geometry section. This also fixed the geometry of the prop shafts on the 1903 model.

Roll control was mechanized to warp top and bottom wings together. A movable “hip” cradle was actuated by the outer thighs and was connected to cables and chains to pull on opposite trailing edges corners of each wing, thus warping only the outer wing panels. Sense was slide right for right roll (RWTEU) and left for left roll (RWTED).

Yaw control was directly linked to roll and was not adjustable by the pilot. Hip cradle slide right resulted in right rudder (TER) and slide left gave left rudder (TEL).

Connection to the rudder was via pull-pull cables and 90 degree bellcranks attached to the lower aft wing warping cable.

Modifications to the test aircraft:

The fabric covering was coated with paraffin/xylene mixture for decreased permeability. Tensioners (turnbuckles) were added to canard elevator linkage. Padding was added to hip cradle and crossbar.

Table B-1
Wright 1902.5 Glider Physical Characteristics

Weight as tested:	Approx 140 lbs
Pilot weights:	105-210 lbs (report author 145 lbs)
Aircraft gross weight:	245 to 350 lbs
Span:	32 feet, 1 inch
Length:	17 feet, 6 inches
Height:	7 feet, 6 inches

Figure B-1
Wright 1902.5 Canard Control System

Source: Ohman, C.P. (Personal digital camera, photo taken October 2003).

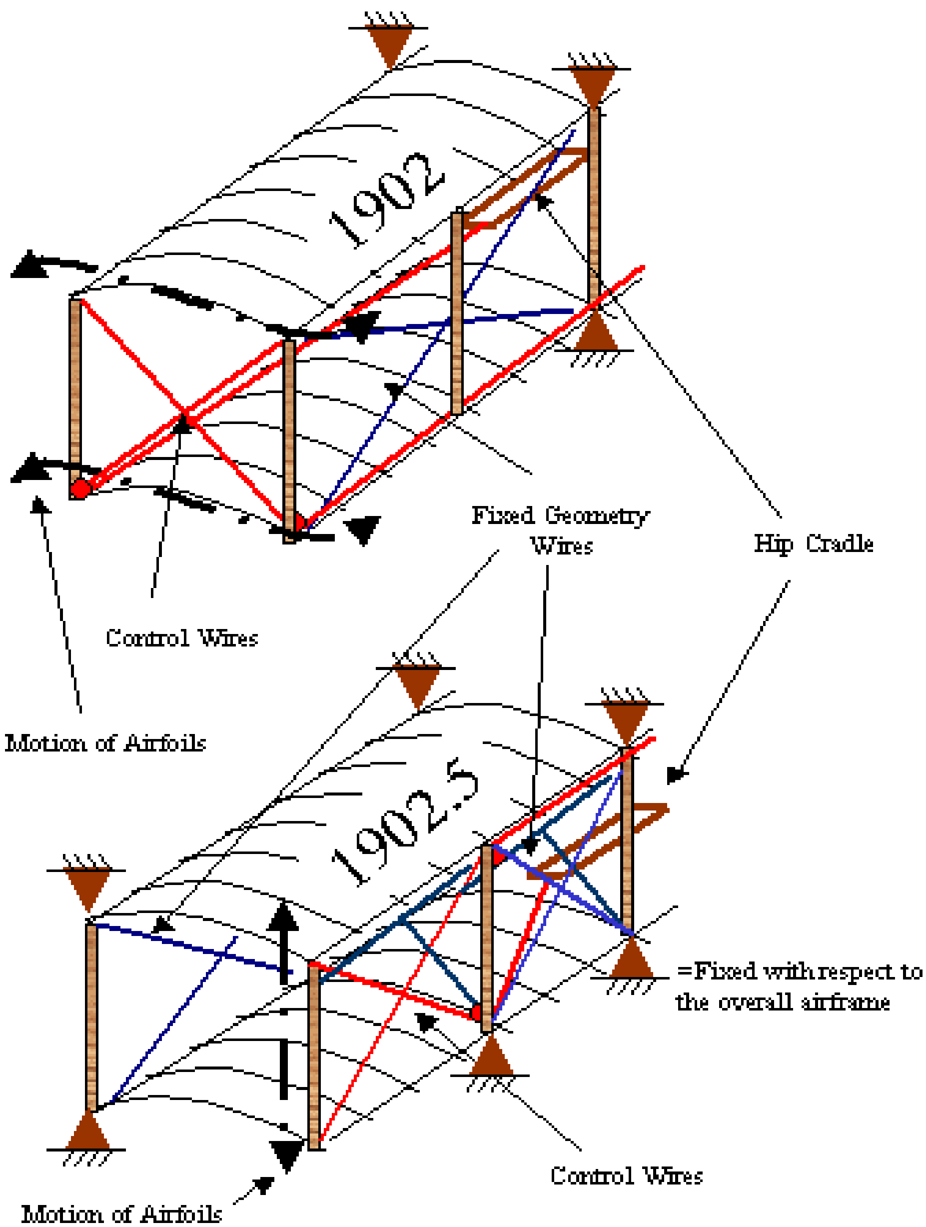


Figure B-2
Comparison Of Wright 1902 And 1902.5 Lateral FCS

Source: Ohman, K. (Digitized Sketch).

APPENDIX C

Detailed Technical Description of the 1903 Replica Wright Flyer

Single place, rail launched, canard elevator biplane aircraft constructed of wood, muslin fabric, string bindings, metal attachment fittings, and wires. The aircraft was assembled following copies of original plans by The Wright Aeroplane Company of Dayton, Ohio, USA. The pilot was situated in the center of the aircraft and supported his weight partially with the padded hip cradle and partially with his hands on the pitch control bar. The feet rested on a wooden box attached to the aft lower wing spar.

Flight Control Description:

Pitch control was affected by a stick attached to a rotary bar linked to the all flying canard elevator. Weight shift by the pilot was not possible for pitch augmentation, as fore or aft movement was impossible in the flying position. Sense was stick forward for pitch down (TEU) canard, twist back (TED) for up. Mechanization was the exact same as the 1902.5 Glider described previously.

Roll control was mechanized to warp top and bottom wings together. A movable "hip" cradle was actuated by the outer thighs and was connected to cables and chains to pull on opposite trailing edges corners of each wing, thus warping only the outer wing panels. Sense was slide right for right roll (RWTEU) and left for left roll (RWTED). Mechanization was the exact same as the 1902.5 Glider described previously.

Yaw control was directly linked to roll and was not adjustable by the pilot. Mechanization was the exact same as the 1902.5 Glider described previously. Hip cradle slide right resulted in right rudder (TER) and slide left gave left rudder (TEL).

Landing Skid / Takeoff Truck system:

A single bicycle hub was mounted on the landing skid connecting bar at the very front of the airframe. Two more hubs were mounted in tandem on a board connected to a yoke type cross member which was free to pivot directionally. The landing skids rested freely on this yoke mechanism, which was designed to fall off the end of the takeoff rail after rotation. The yoke was not designed to remain with the aircraft in flight. The takeoff rail consisted of a number of 2 x 6 inch boards topped with an interlocking flat steel plate of approximately 2 x 1/8 inch dimension. This flat steel plate was replaced during the Dayton, Ohio trials by channel sections of 1/8 inch steel measuring 2 x 3/8 inch.

Modifications to the test aircraft:

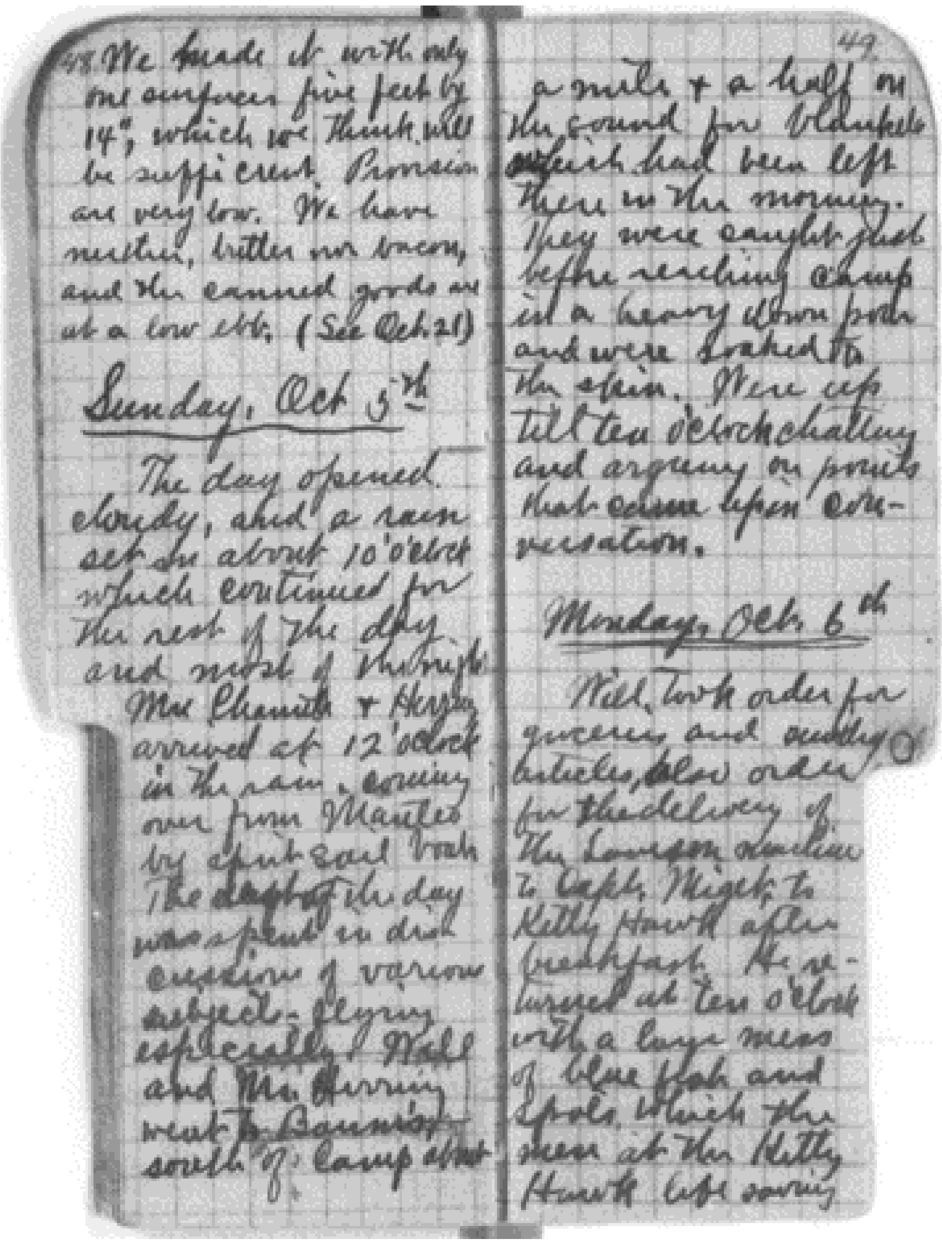
For the best predicted and flying qualities, an initial 75 pounds lead shot ballast was attached to front cross member which yielded a CG with nominal pilot of approximately 19% MAC. This was reduced gradually to 25 lbs by the end of the program for a CG of 25 % MAC. The original Wright designed 16-12 HP four cylinder engine was replaced by a 20 HP Briggs and Stratton vertical shaft V-Twin engine through a clutchable 90 degree angle drive reduction gear box with approx 3-1 ratio to the output gear. This was later replaced by a similar, but more powerful 25 HP model. Out of the 90 degree drive, an historic Wright gear reduction of 2.87 to 1 at the propeller was used. Dual pitch control cables with tensioning turnbuckles were used, similar to the 1902.5 arrangement. The wing surfaces coated with paraffin-xylene mix. For enhanced pilot safety, additional bracing on landing skids and strengthened ribs surrounding the pilot area were used. The fabric covering was coated with paraffin/kerosene mixture for decreased permeability. Lastly, a safety harness was attached around the pilots shoulders to the lower rear wing spar to mitigate possible injuries from ejection following nose-low crashes.

Table C-1
Wright 1903 Flyer Physical Characteristics

Weight as tested:	Approx 625 lbs
Pilot weights:	105-210 lbs (report author 145 lbs)
Aircraft gross weight:	730 to 835 lbs
Span:	40 feet, 4 inches
Length:	21 feet, 1 inch
Height:	9 feet, 4 inches

APPENDIX D

Selected Historical Wright Documents


48. We made it with only one surface five feet by 14", which we think will be sufficient. Provisions are very low. We have neither butter nor bacon, and the canned goods are at a low ebb. (See Oct 21)

Sunday, Oct 5th

The day opened cloudy, and a rain set in about 10 o'clock which continued for the rest of the day and most of the night. Mr Chanute & Herring arrived at 12 o'clock in the rain, coming over from Manteo by sail boat. The ~~day~~ rest of the day was spent in discussion of various subjects—flying especially. Will and Mr. Herring went to Baum's south of camp about

49

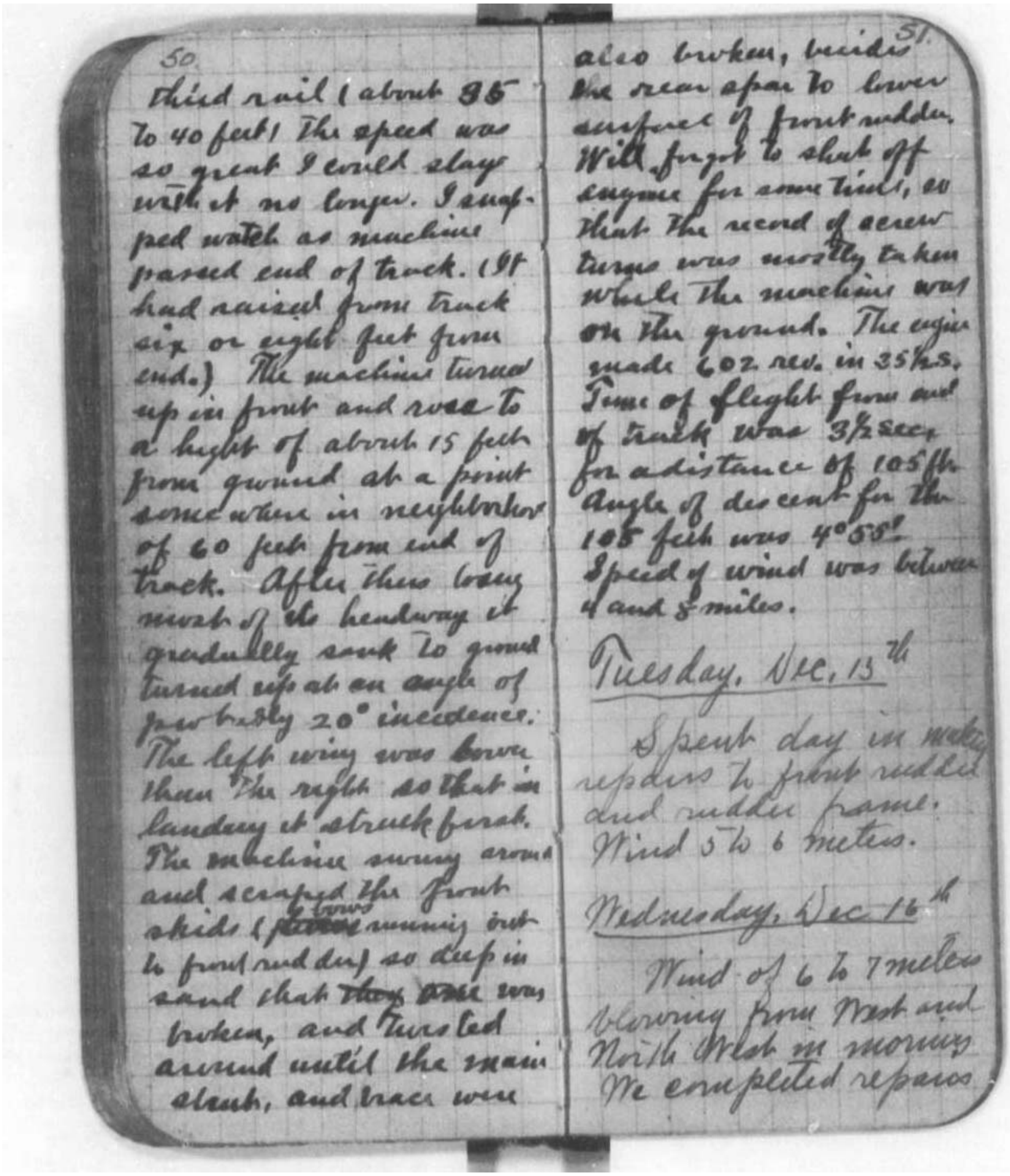
a mile & a half on the sound for blankets which had been left there in the morning. They were caught just before reaching camp in a heavy down pour and were soaked to the skin. Were up till ten o'clock chatting and arguing on points that came up in conversation.

Monday, Oct. 6th

Will took order for groceries and sundry articles, also order for the delivery of the Lamson machine to Capt. Midgett to Kitty Hawk after breakfast. He returned at ten o'clock with a large mess of blue fish and spots, which the men at the Kitty Hawk life saving

Figure D-1
October 5th and 6th 1902 Orville Wright Diary

Source: Library of Congress. (viewed 2004, January). *Papers of Orville and Wilbur Wright* [WWW document]. URL
http://memory.loc.gov/master/mss/mwright/01/0100X/0028



50.

third rail (about 35 to 40 feet) the speed was so great I could stay with it no longer. I snapped watch as machine passed end of track. (It had raised from track six or eight feet from end.) The machine turned up in front and rose to a hight of about 15 feet from ground at a point somewhere in neighborhood of 60 feet from end of track. After thus losing most of its headway it gradually sank to ground turned up at an angle of probably 20° incidence. The left wing was lower than the right so that in landing it struck first. The machine swung around and scraped the front skid (~~pieces~~ bows running out to front rudder) so deep in sand that ~~they~~ one was broken, and twisted around until the main strut, and brace were

51.

also broken, beside the rear spar to lower surface of front rudder. Will forgot to shut off engine for some time, so that the record of screw turns was mostly taken while the machine was on the ground. The engine made 602 rev. in 35½ s. Time of flight from end of track was 3½ sec. for a distance of 105 ft. Angle of descent for the 105 feet was 4°55'. Speed of wind was between 4 and 8 miles.

Tuesday, Dec. 15th

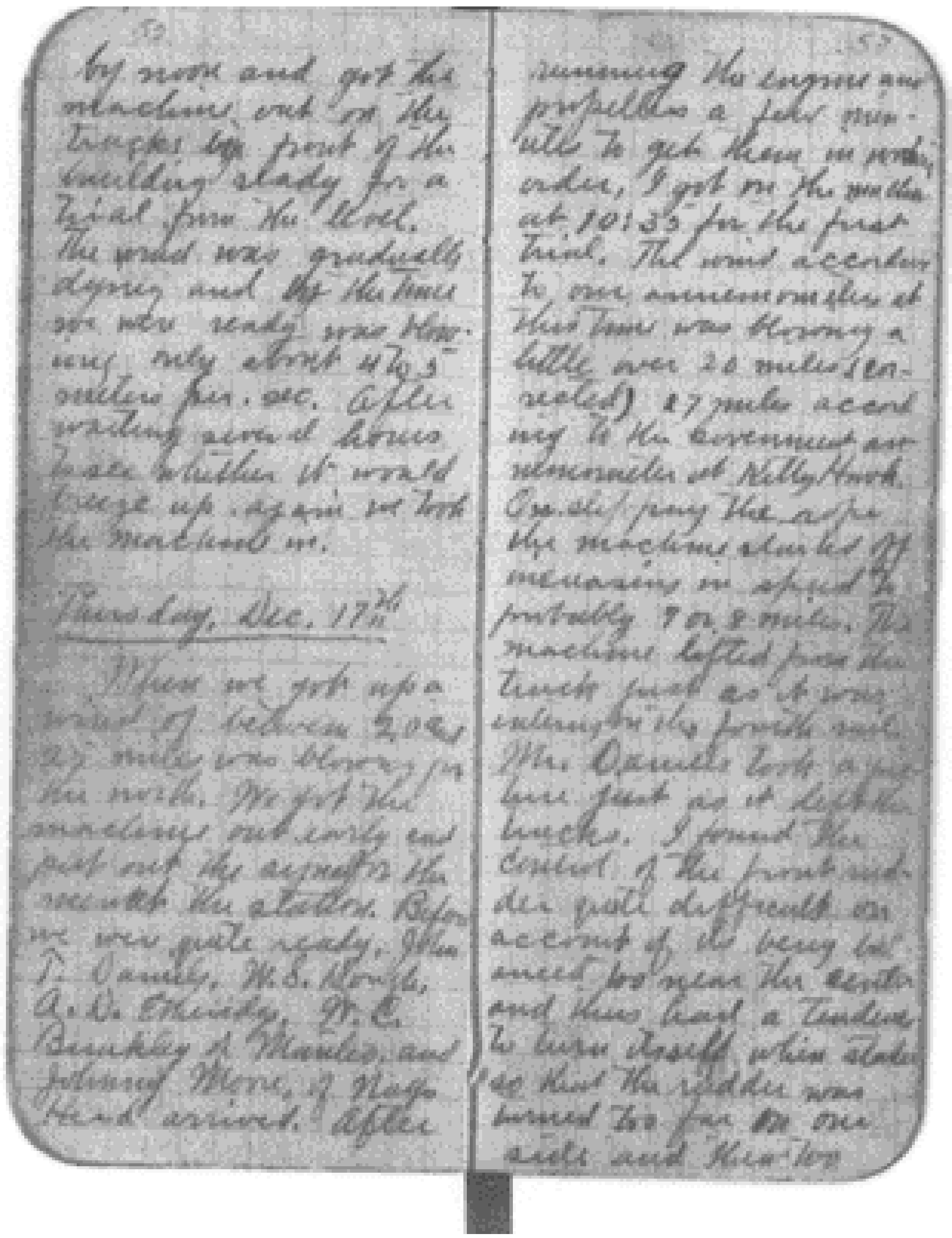
Spent day in making repairs to front rudder and rudder frame. Wind 5 to 6 meters.

Wednesday, Dec 16th

Wind of 6 to 7 meters blowing from West and North West in morning. We completed repairs

Figure D-2
December 14th, 15th, 16th 1903 Orville Wright Diary

Source: Library of Congress. (viewed 2004, January). *Papers of Orville and Wilbur Wright* [WWW document]. URL http://memory.loc.gov/master/mss/mwright/01/01007/0027.jpg



by noon and got the machine out on the tracks in front of the building ready for a trial from the level. The wind was gradually dying and by the time we were ready was blowing only about 4 to 5 meters per. sec. After waiting several hours to see whether it would breeze up again we took the machine in.

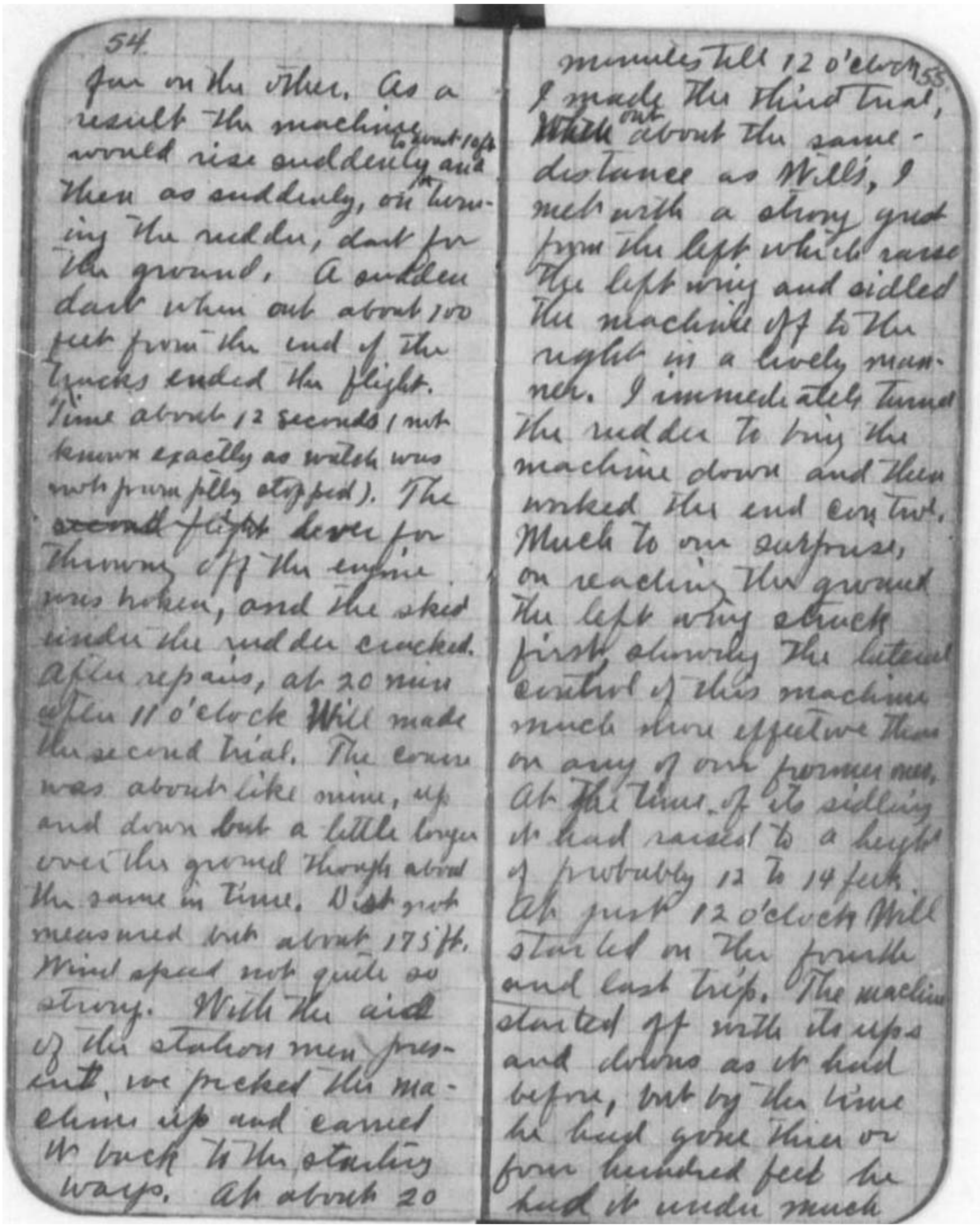
Thursday, Dec. 17th

When we got up a wind of between 20 and 25 miles was blowing from the north. We got the machine out early and put out the signal for the men at the station. Before we were quite ready, John T. Daniels, W. S. Dough, A. D. Etheridge, W. C. Brinkley of Manteo, and Johnny Moore of Nags Head arrived. After

running the engine and propellers a few minutes to get them in working order, I got on the machine at 10:35 for the first trial. The wind according to our anemometers at this time was blowing a little over 20 miles (corrected) 27 miles according to the Government anemometer at Kitty Hawk. On slipping the rope the machine started off increasing in speed to probably 7 or 8 miles. The machine lifted from the truck just as it was entering on the fourth rail. Mr. Daniels took a picture just as it left the tracks. I found the control of the front rudder quite difficult on account of its being balanced too near the center and thus had a tendency to turn itself when started so that the rudder was turned too far on one side and then too

Figure D-3
December 17th 1903 Orville Wright Diary

Source: Library of Congress. (viewed 2004, January). *Papers of Orville and Wilbur Wright* [WWW document]. URL http://memory.loc.gov/master/mss/mwright/01/01007/0028.jpg



54

far on the other. As a result the machine would rise suddenly to about 10 ft and then as suddenly, on turning the rudder, dart for the ground. A sudden dart when out about 100 feet from the end of the tracks ended the flight. Time about 12 seconds (not known exactly as watch was not promptly stopped). The ~~second flight~~ lever for throwing off the engine was broken, and the skid under the rudder cracked. After repairs, at 20 min after 11 o'clock Will made the second trial. The course was about like mine, up and down but a little longer over the ground though about the same in time. Dist not measured but about 175 ft. Wind speed not quite so strong. With the aid of the station men present, we picked the machine up and carried it back to the starting ways. At about 20

55

minutes till 12 o'clock I made the third trial. ~~When~~ out about the same distance as Will's, I met with a strong gust from the left which raised the left wing and sidled the machine off to the right in a lively manner. I immediately turned the rudder to bring the machine down and then worked the end control. Much to our surprise, on reaching the ground the left wing struck first, showing the lateral control of this machine much more effective than on any of our former ones. At the time of its sidling it had raised to a height of probably 12 to 14 feet. At just 12 o'clock Will started on the fourth and last trip. The machine started off with its ups and downs as it had before, but by the time he had gone three or four hundred feet he had it under much

Figure D-4
December 17th 1903 Orville Wright Diary (Cont)

Source: Library of Congress. (viewed 2004, January). *Papers of Orville and Wilbur Wright* [WWW document]. URL http://memory.loc.gov/master/mss/mwright/01/01007/0029.jpg

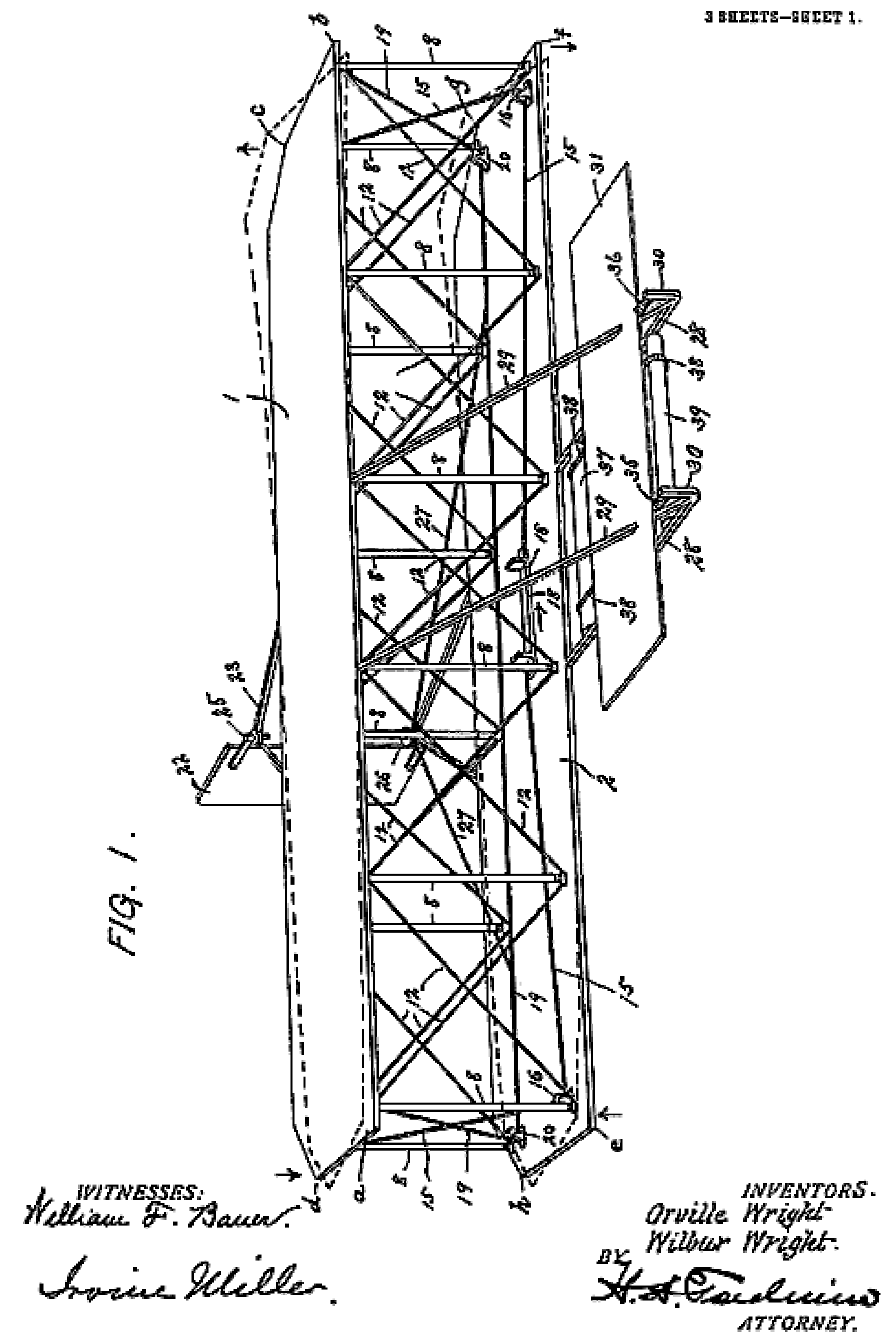


Figure D-5
Page One Of Wright 1906 Patent

Source: Mississippi State University. (viewed May 2004). 1906 *Wright US Patent #821,393* [WWW document]. URL http://invention.psychology.msstate.edu/i/Wrights/WrightUSPatent/WrightPatent.html

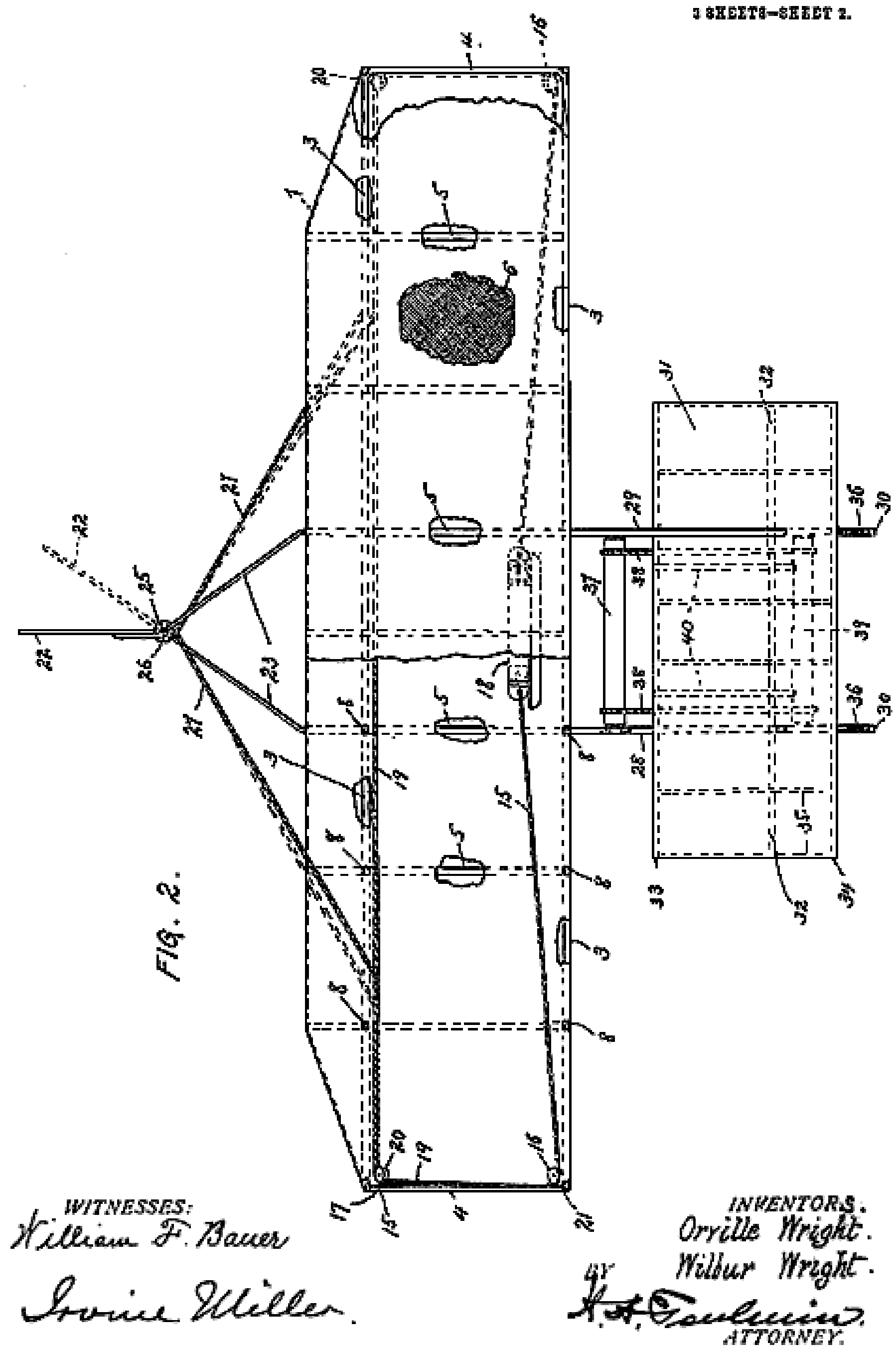


Figure D-6
Page Two Of Wright 1906 Patent

Source: Mississippi State University. (viewed May 2004). 1906 *Wright US Patent #821,393* [WWW document]. URL http://invention.psychology.msstate.edu/i/Wrights/WrightUSPatent/WrightPatent.html

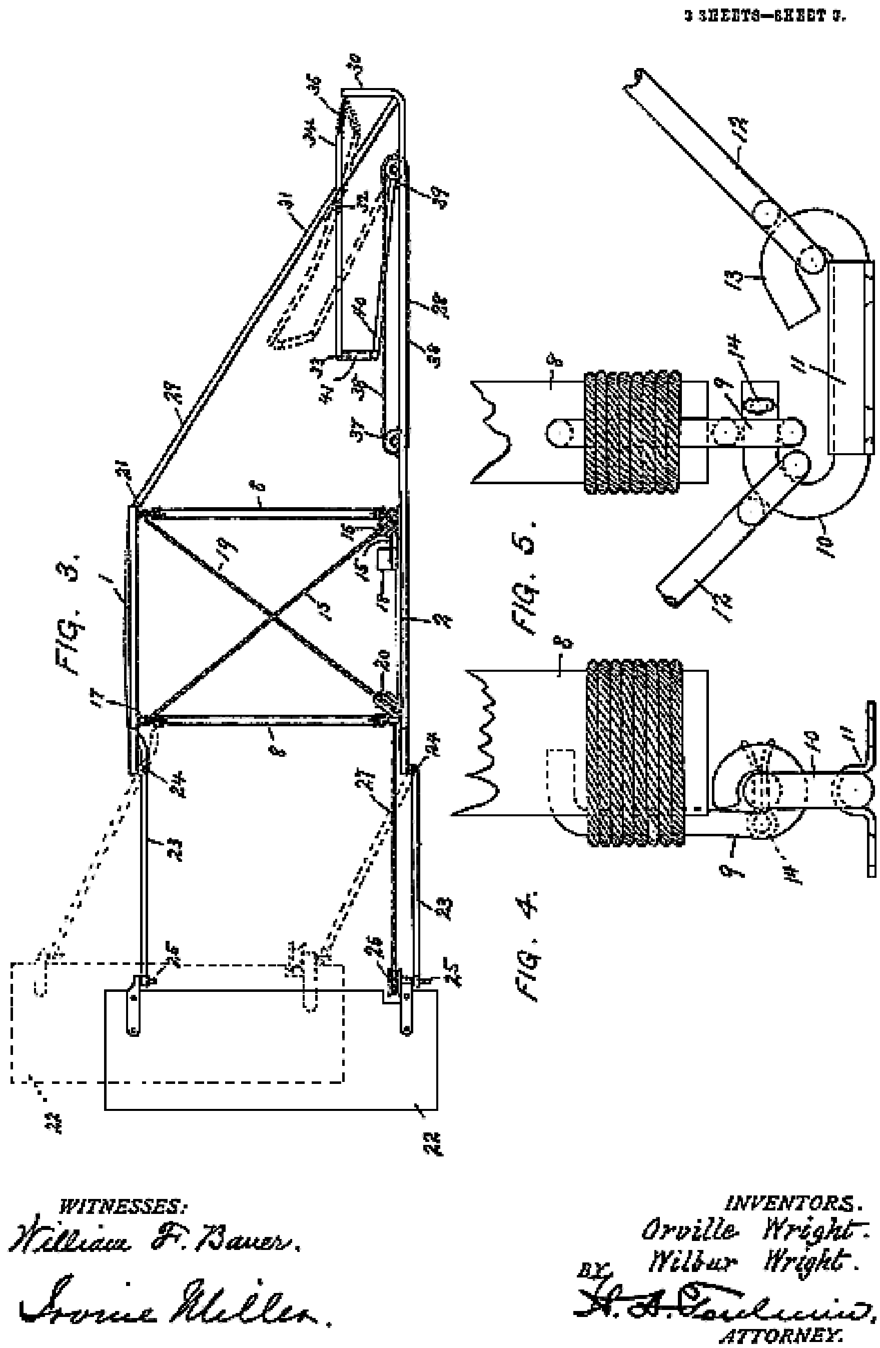


Figure D-7
Page Three Of Wright 1906 Patent

Source: Mississippi State University. (viewed May 2004). 1906 *Wright US Patent #821,393* [WWW document]. URL http://invention.psychology.msstate.edu/i/Wrights/WrightUSPatent/WrightPatent.html

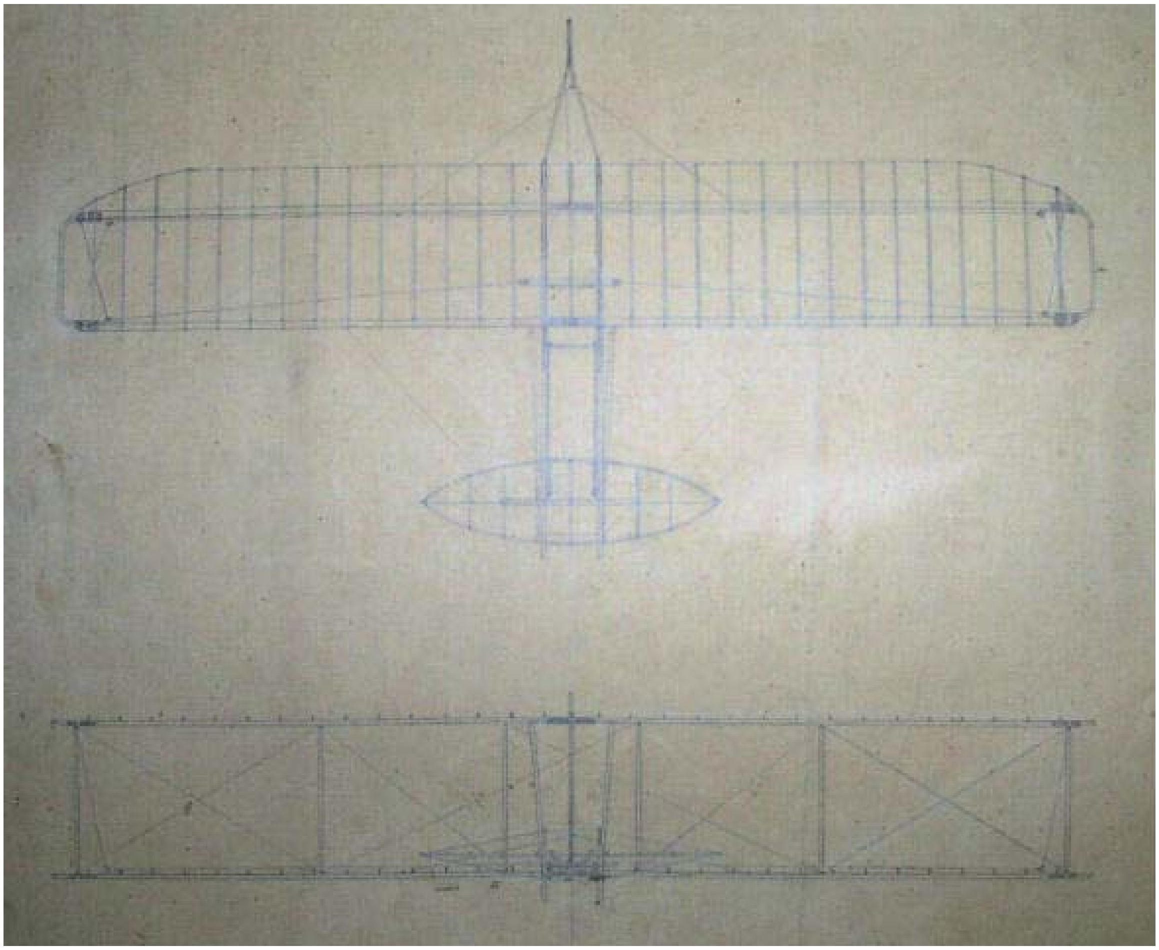


Figure D-8
1934 Army Air Corps Engineering Plans

Source: Engler, Nick. (viewed May 2004). *1902 Wright Glider* [WWW document]. URL http://www.first-to-fly.com/Adventure/Workshop/building1902.htm

VITA

Klas started flying at age 12 in his hometown of Athens, Tennessee where he logged his first instructional flight in a Piper Super Cub. Throughout high school he continued to fly, achieved Eagle rank in the Boy Scouts, and competed in varsity sports. College took him to the Citadel in Charleston, South Carolina where he majored in Civil Engineering and was a member of the sailing team and Navy ROTC. Following graduation from the Citadel as a Distinguished Naval Graduate, Klas was commissioned an Ensign and completed basic flight instruction at Training Squadron Two (VT-2) in Milton Florida. Intermediate and Advanced flight training were completed at VT-19 and VT-7 respectively in Meridian Mississippi in the T-2C Buckeye and TA-4J Skyhawk. After winging, he spent time as a staff pilot in the T-34C back at Whiting Field. He completed the Fleet Replacement Squadron at NAS Cecil Field in Jacksonville Florida and was assigned to Strike Fighter Squadron Eighty Seven (VFA-87) where he completed two Mediterranean Cruises and logged combat hours in support of Operations Deliberate Force, Southern Watch, Deny Flight and others. During this tour he was awarded the Strike Flight Air Medal and Navy Commendation Medal with Combat "V". Following this fleet tour, he moved to Patuxent River, Maryland where he graduated with distinction from the United States Naval Test Pilot School (USNTPS). Afterward he worked at the Strike Aircraft Test Squadron (now VX-23) on projects including noise and vibration / safe separation / envelope expansion / carrier suitability test flights with AIM-9X, JDAM, ATFLIR and FA-18E/F Super Hornet. After a year of test work, he was invited to return to USNTPS as a flight instructor and subsequently awarded Instructor of the Year. Klas was transferred to CVW5 in February 2001 and served as Maintenance Officer then

Operations Officer on three WESTPAC deployments and one to CENTCOM. On this last deployment, he flew 25 combat missions in support of Operations Southern Watch and Iraqi Freedom. During this tour he was awarded Numerals 2 and 3 for the Strike Flight Air Medal, the Air Medal with Bronze Star and a Navy Commendation Medal. After departing VFA-195, he was awarded the CDR Michael Hoff Award for the Chief of Naval Air Pacific Attack Aviator of the Year for 2002. Currently Klas is the Department Head for Ship Suitability at VX-23. All told, he has flown over 2700 hours in 57 different military and civilian aircraft and has over 650 arrested landings on 12 aircraft carriers. He is married to the former Ms. Julie Henderson of Mechanicsville, Maryland and has two daughters, Kelsey and Beth. Hobbies include sailing, biking, hiking and playing the guitar.