Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1990 Volume VII: What Makes Airplanes Fly? History, Science and Applications ofAerodynamics

The Science of Flight in Relationship to Birds and Gliders

Curriculum Unit 90.07.09
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I. INTRODUCTION/RATIONALE

"The Science of Flight in Relationship to Birds and Gliders" is a unit based upon the scientific aspects of how birds and gliders actually fly. Its fundamental goal, therefore, is to answer one of the most often asked question of children, "how do birds fly?". In addition to answering that question, I intend to show the student that man has somewhat imitated bird's flight with an engineless machine—the glider.

The first section of the unit takes an indepth look at birds, including such concepts as: how the bird's feathers are formed and the role they play in flight in relationship to the wings. Within this section the reader will learn why there are different wing types on birds, as well as what different types of flight birds can perform. The reader will also learn about the science of aerodynamics associated with the bird.

Concluding the unit, students will learn about man's first form of flight which truly imitated the free-flight of birds—the glider. This section starts off with a brief history of gliders where students will learn about such important contributions to the invention of the gilder such as: Sir George Cayley, Jean Marie LeBris, Otto Lilienthal and others. Afterwards the unit will focus on how gliders actually fly. Students will discover that the science of bird flight played a remarkable role in man's discovery of the glider. The similarities of the science of flight between the bird and the glider is phenomenal.

II. TEACHING OUTLINE/UNIT OBJECTIVES

"The Science of Flight in Relationship to Bird's and Gliders" is a unit written for the middle school grades of five through eight. Since it is a unit based on science, hands-on scientific activities are included at the end of each section. As previously stated, this unit is divided into two sections. Therefore, I have included the objectives of each section separately so that the teacher will know what their students are to achieve for each section. The objectives within each section are as follows:

SECTION I:. THE FLIGHT OF BIRDS

The student will be able to:

* identify the part of a feather and describe how it grows.
* list and identify the five different types of feathers.
* describe the system of barbules in feather construction.
* state what part of the wing that the primary and secondary feathers are located.
* list the three muscles that are responsible for moving the upward and downward.
* explain how the bird can lift itself into the air.
* describe the five different types of flight.

SECTION II: GLIDERS

The students will be able to:

* identify what roles Sir George Cayley, Jean Marie LeBris, Otto Lilienthal and John Montgomery played in the history of the glider's development.
* list and describe the three main parts of the glider.
* list and describe the three ways in which the glider is launched into the air.
* describe how hill lift and thermal convection enables the glider to fly.

SECTION I: THE FLIGHT OF BIRDS

A) THE FUNCTION AND FORMATION OF FEATHERS

The feather is the primary part of the bird which makes it unique from any other animal on earth. Feathers grow straight out of follicles in the skin, much like the way human hair and animal fur grow (1). Feathers grow from the follicles which are grouped in a pattern of tracts along the bird's body. Birds look as though they are covered everywhere with feathers because they overlap, covering the bald areas between the tracts.

The first stage of a feather's growth is a small pimple called a papilla—a kind of mound surrounded by a tiny trough. Papillae begin to appear on the skin of the embryo chick after about a week of incubation in the egg. By the time the bird hatches from the egg an epidermal cell called Malpighian is formed, which eventually becomes the actual feather (2).

The short basal part of the feather is called the calamus. There is an opening at the bottom of the calamus called the lower umbilicus. During the feather's short period of growth, blood enters the young feather. Once growth is completed, the lower umbilicus is sealed off and blood no longer enters the feather. Once the feather is sealed off each feather can be moved by a separate muscle situated in the skin (3).

At this point the new feather will become one of six types: contour, down, semi-plume, bristle, or powder down. The longer, stiffer feathers that covers the adult bird's body are known as contour feathers because they define the shape of the bird. Down and semi-plumes feathers are pieces of fluff that lie underneath the contour feathers for insulation and padding. Filoplume feathers are made up of a thin shaft with a few short barbs of barbules at the tip. They have a lot of free nervous endings connected to pressure and vibration receptors around the follicles. Bristle feathers have a very stiff rachis and few, if any barbs. They function as eyelashes and aid birds which catch flying insects.

Even though the quantity of each type of feather a bird contains is different, the basic construction of feathers is the same for all birds. The shaft which projects from the skin contain many branches on both of its sides. Together they form a flat surface called the vanes. The rachis carries the vanes of the feather. Each vane is made up of a row of barbs arranged side by side. The barbs are connected by smaller branches called barbules. The barb and barbules are linked together by means of tiny hooklets called barbiceli (4).

The system of barbules is one of nature's most amazing bits of engineering. This structural device enables the feather to be waterproof and cut air precisely during flight. A large part of a bird's day is spent maintaining the system of barbules (5). (See Figure I at the end of this section).

(B) THE WINGS

Amazingly, the bird's wing physically compares to the human hand and arm which is displayed at the end of this section in Figure 2. The wings of a bird are composed of the humerus or the upper arm, the radius and ulna which makes up the forearm, and the wrist and finger bones. The wrist and handbones are fused together in order to provide a firm support base for the primary feathers. The chief function of the primary feathers is to propel and maneuver the bird during flight (6). Whereas the secondary feathers are primarily responsible for lift, which will be discussed further in a later section of this paper.

In addition to the primary and secondary feathers, the hand portion of the wing also supports a few small feathers on the thumb, or first digit. The thumb portion of the wing is known as the alula, and the feather makes up the bastard wing. The bastard wing's function is to produce wing slots in order to increase the amount of air flow over the wing during slow labored flight (7).

The wing is also made up of muscles, tendons, nerves and connective tissue. It is through these items that the wing is able to move, even though the large pectorial muscle is accredited with doing most of the work (8). The pectorial muscle is the largest muscle in the bird's body. It covers most of the area between the breast bone and the base of the wing. When the large pectorial muscle contracts, the wing is pulled downward. Contrasting the large pectorial muscle is the small pectorial and deltoid which are responsible for raising the wing. The deltoid muscle is also responsible for rotating the wing back out from the leading-edge-down position into which the large pectorial muscle turns it. The three muscles—the deltoid, large and small pectorial—provide the power needed for moving the wing (9). Even though the tendons, which run through a hole in the bones aid the large pectorial muscle in pulling the wing upward.

The skin made up of connective tissue covers all the above mentioned components of the wing. Furthermore, it is the skin in which the feather of the wings are inserted. Total control and proper functioning of the complicated appendage—the wing—is left up to the central nervous system which includes the brain and the spinal cord.

(C) THE FOUR DIFFERENT TYPES OF BIRD WINGS

The wings of birds vary in both shape and size. Both characteristics depend largely upon the function and the habitat of the bird (10). Wings have been classified under one of the following four groups: elliptical, high speed wings, high-aspect ratio, or slotted high-lift wings.

Elliptical wings are found on birds which live in a forested environment where they are forced to dodge quickly in and out of obstructions. Birds characterized with this type of wings have a low aspect ratio which means that the length of the wing divided by the width yields a low number. They are also highly cambered (flatter wing section or shaped) and the outer primary feathers are slotted. Elliptical wings are found in most gallinaceous species, as well as doves, passerines and woodpeckers.

The high-aspect ratio wings can be identified on birds by its length. The length of the wing greatly exceeds the width. Characteristically, this wing type is long, narrow and rarely has wing tip slotting. High-aspect ratio wings are most commonly found in soaring seabirds such as shearwaters, albatrosses and frigate birds. Birds who possess this wing type are also noted for their long distance gliding abilities.

High speed wings are found on birds that make long migrations. These wings have a low camber or a flattish profile and a fairly high aspect ratio. Such wing types taper to a relatively slender elliptical tip and tend to be swept backwards like the wings of a high speed jet fighter plane. The best examples of high speed wings are found on hummingbirds, swallows, falcons, sandpipers and plovers.

The fourth type of wings are the slotted high-lift wings. They have a moderate aspect ratio, deep camber and noticeable slotting in the wing tip. This type of wing produces an efficient soaring wing for birds that generally carry heavy objects for consumption such as owls, vultures, hawks and eagles.

(D) THE BIRD'S TAIL

Even though the wing of the bird plays an important role in bird flight, it is not totally responsible for flying. Since the wings are generally located just in front of the bird's center of gravity, the body tends to move down towards the earth. During flight, the bird's lowered tail is acted upon by the horizontal air stream, and is lifted in a compensating fashion. This provides the tail with great maneuvering power. The tail of the bird also aid the wings in supporting, steering, balancing and braking the body during flight (11).

(E) AERODYNAMICS OF BIRD FLIGHT

In order for a bird to fly it must obtain an upward force which is known as lift. The construction of a bird's wing enables the bird to achieve lift. A wing which is shaped to achieve lift is called an aerofoil. The leading edge and the upper surface is more convexed than the lower surface.

When air strikes the leading edge of the wing it divides, some air passes underneath the wing while the remainder passes across the upper surface. Since the upper surface of the wing is curved, it has a longer surface than the underside of the wing. In order for air to travel to the rear of the wing at more or less the same time as the air on the underside, the air on the upper surface must travel faster than the air underneath the wing. The faster air travels across a surface the lower the pressure it exerts on that surface, as a result the wing's upper surface experiences a lower pressure than under the surface and produces lift (12).

Lift, therefore, can only be produced by the wing when the flow of air is smooth over the surface. Lift is lost when the flow of air over the wing is separated—this occurrence is known as stalling. Stalling occurs when the wing is held at too high of an angle and the flow of air breaks away from the upper surface.

Air passing over the wing also exerts another force known as drag on the wing. Drag is the backwards pressure or force of the air opposing the wing in its movement through the air. Drag is equivalent to the amount of the bird's wing which is exposed to the wind. The flatter the bird's wing the less drag there will be, while the steeper the angle at which the wing is tilted (known as the angle of attack), the greater the drag. Drag on the wing can be caused by the air that has passed along the lower surface of the wing flowing up over the trailing edge of the wing and into the lower pressure area on the upper surface. This upward flow is strongest at the end of the wing and is referred to as wing-tip vortex. The flow of air caused by the wing-tip vortex spreads inward along the trailing edge of the wing and interrupts the desired smooth movement of air for a considerable distance causing drag (13). Both drag and lift are effected by the area and shape of the wing, the area of attack, and by speed.

Forward propulsion, known as thrust, is obtained by the large pectoral muscles when they drive the wing downward. In order to fly forward the downbeat must provide both upward and forward movement of the bird so that it both stays airborne and moves forward against the resistance provided by drag. Thrust is achieved by the flapping of the bird's wing. As the wing is flapped the feathers tend to bend so that the backward edge of the wing is above the bones. (The wing bones are in the leading edge of the wing, thus the trailing edge is the feather.) As a result, even though the wing beats downward because of its shape, it pushes the air both downward and backwards, thus pushing the bird in the opposite direction-forward.

(F) THE FIVE DIFFERENT TYPES OF BIRD FLIGHT

There are five major types of bird flight, even though four of the five methods are closely related. The five major types of flight are known as flapping, gliding, soaring, fluttering and hoovering flight. Of the five, the mechanics of flapping flight is the most difficult for scientist to understand (14).

Flapping flight is the rapid and vigorous beating of the bird's wing up and down against its body. It is this type of flying that enables the young bird to leave its nest and begin to learn the more advance flying techniques. Flapping flight is also the one used by birds when they take off in order to propel themselves into the air. The difficulties of understanding flapping flight becomes apparent when one considers all the aspects involved in this type of flight. A beating wing yields under pressure causing it to be very flexible. The shape, camber, expanse, sweepback, and even the position of the individual feathers may change pronouncedly. The different parts of the wing change in velocity and angle of attack during a single beat (15). The aforementioned variables are only a few of the mechanics of flapping flight that scientist are attempting to fully understand. However, some of the principles of flapping flight have been discovered largely due to high speed photography.

During gliding flight, the wings are stretched out stiffly into the air. The bird loses height due to the gravitational pull of the earth, however, gravity also gives the bird the advantage of acceleration during gliding flight. A good glider can glide a long ways horizontally with minimal loss of height by holding its wings at a slight angle to an air current, which allows the air to flow faster over the upper surface than over the lower surface of the wing thus creating lift. At the same time the resistance to moving air tends to drag the wing backwards. True gliding flight is made possible when lift and drag forces are adjusted to be equal to the weight of the bird, which is achieved by the angle at which the bird holds its wing causing the wind to hit it in a certain way (16).

There are two basic ways in which a bird can glide when the air is still. First it can launch itself from a perch and open its wings. This way the bird uses the energy provided by gravity so that by losing height it can travel forward. Secondly, it can depend upon thermals or obstruction currents like the glider plane does. Thermals are rising columns of warm air coming from the earth's surface. Whereas, obstruction currents are caused when wind blows against large solid objects like mountains, cliffs and buildings and causes the wind to be pushed upward.

Soaring flight covers any technique of flight where energy is extracted from movement of atmospheric wind and converted into kinetic energy of the bird (17). Birds use soaring for two reasons. First it can be used to stay airborne using little energy while looking for food. Secondly, it is used for cross-country flight which offers an alternative method of travel instead of depending solely on power flight such as flapping.

The simplest method of soaring is slope soaring, where the birds fly in regions of rising air caused by the upward deflection of wind over a slope. Smaller birds can also use ocean currents for slope soaring. Two different types of wings seem to be best suited for soaring: the wide expansive wings of vultures and hawks, or the long narrow wings of gulls and albatrosses.

Fluttering flight generally refers to a bird that can remain stationary in one spot in the air without the help of a strong head wind (18). The hummingbird hanging suspended over a flower is an excellent example of fluttering flight. Some birds flutter at the tips of branches as they pick off insects that may gather there, such birds include the kinglets and warblers. Some species such as skylarks, purple finches and white-winged crossbills often give the most ecstatic part of their flight songs during fluttering flight.

Hoovering flight closely resembles fluttering flight. However, hoovering flight requires assistance from headwinds (19). During hoovering flight, the tail of the bird is usually fanned and pointed downward. The rear of the body is tilted downward, and the speed and angle of the wingbeats are regulated to support the bird yet prevent the wind from pushing the bird backwards. The osprey, hummingbird, common tern and belted kingfisher usually display excellent examples of hoovering flight.

FIGUREI The System of Barbules in a Feather
(figure available in print form)
FIGUREII Comparison of Bird's Bone Structure to the Human's.
(figure available in print form)

LESSON PLAN I

I. OBJECTIVES:
(1) The student will draw and label the parts of a feather.
(2) The student will observe the barbule system and the waterproofing quality of a feather.
II. NOTE TO THE INSTRUCTOR:
This lesson may be performed with a magnifying glass or a hand lens, but the student will get a much better view of the feather through a microscope.
III. MATERIALS NEEDED:
(1) magnifying glass or microscope
(2) primary or secondary feather
IV. PROCEDURE:
(1) Have the student look at a feather underneath a microscope.
(2) Have the student explain orally what they observe once they view the feather.
(3) Have the student draw and label the feather.
(4) Have the student draw the barbule system of the feather, including the barbule, barbiceli and barb.
(5) Upon completion of their drawings, the students will run water over the feather and discuss what they have observed.

LESSON PLAN 2

I. OBJECTIVES:

(1) The student will locate and identify the following bones: the humerus, ulna, radius, fused metacarpal, alula, and the second digit.

II. NOTE TO THE INSTRUCTOR:

Chicken wings from the store may be used for this experiment. Dissection knives or are is not necessarily required for this activity, scissors may be used instead. However, the type of scissors needed are expensive, therefore, dissection knives are a less costly alternative depending upon your student maturity level.

III. MATERIALS NEEDED:

(1) dissection tray (2) dissection knife or scissors (3) chicken wings

IV. PROCEDURE:

(1) Prepare a diagram of a bird's wing with the bones labeled for each group. (See Figure 3).

(2) Show the students how to properly cut or dissect the chicken wing.

(3) Have the students carefully remove the skin from the chicken wing and view the muscle tissue under the chicken wing.

(4) Have the students carefully cut through the muscle tissue until they can see the bones.

(5) Have the students draw and label the bones on a sheet of paper.

LESSON 3 FEATHER OBSERVATION

I. OBJECTIVES:

(1) The student will identify the type of flight that a bird is using.

(2) The student will identify the type of wing a bird has.

II. NOTE TO THE INSTRUCTOR:

This lesson can be done while sitting outside of your school building, or in the neighborhood park. I chose to take the class to Lighthouse Park which is known for its bird migratory sites.

III. PROCEDURES:

(1) Divide the students into groups of four. Assign someone in the group to keep data.

(2) Tell the students to quietly identify the wing type and flight of the birds they observe in the park.

(3) Once the investigation has been completed, record the class data on the board upon arrival into the classroom.

SECTION IV: GLIDERS

(A) HISTORY OF GLIDERS

The evolution of gliders originated from man's fascination with bird flight. As early as the 1800's, man observed, envied and began to imitate the free flight of birds. Sir George Cayley, a British scientist, was the first man to interpret flight through terms of mathematics (20). He also discovered the secret of flight through studying the bird. He demonstrated that a bird feather set at a certain angle could generate lift when it moved through the air or when air moved around it. Applying what he learned from this experiment, he was the first person to design a biplane glider that remained briefly in the air.

Jean Marie LeBris, a Breton sea captain, went as far as to kill an albatross to examine its wings. From his study of the albatross he built what became known as the LeBris glider (21). It was towed into the air like a kite via the power of a horse in 1857.

Otto Lilienthal, a German scientist, inventor and engineer, was the first great exponent of gliding (22). He made more than two thousand successful flights in his bird-like glider composed of peeled willow wands covered with waxed cotton cloth. Lilienthal kept records of each of his flights, constantly improving the design of his gliders. He finally started covering distances of about seventy-five feet above the ground. On August 9, 1896 he lost control of one of his aircrafts and fell to his death. Two of his followers, Percy Pilcher of England and Octave Chanute of America, carried on his works with a great deal of success.

John Montgomery was the first American to build a successful glider, and the first to be able to control his aircraft in the air. He started building and experimenting with gliders in 1883. Montgomery made his first public demonstration of his aircraft in 1905. As opposed to the other hang gliders jumping off dunes and cliffs, Montgomery used hot air balloons to lift his gliders into the air. Once the hot air balloon raised the glider to an appropriate height into the air, the balloon was released and Montgomery piloted the glider to earth.

Today, depending on good conditions, gliders can travel for several hundred miles. The longest recorded distance that a glider has traveled was in 1964, which was 647 miles (23). Unlike the late 1800's when gliders were categorized as single or double winged, modern gliders are broadly categorized into two divisions—standard and open class. Standard class are gliders which are easy to fly, light weight, and cheaply made. They are strictly used for club or private use. Whereas, open class gliders are made for competitive flying and are very expensive to produce.

(B) PARTS OF GLIDERS

Most gliders have three main parts designed in a streamlined fashion which enables it to knife through the air with minimal amounts of air resistance (drag). The three main parts of a glider are the wings, body and tail assembly.

The wings of gliders are very narrow. The narrow design reduces the drag at the glider's wing tip. As the glider flies through the atmosphere, air tends to flow in opposite directions along the length of the wings. Air along the tip of the wing tends to flow inward, whereas air along the bottom of the wings tends to flow outward. The opposite flow of air causes a swirling stream of air called a vortex to form behind each wing tip and hold the aircraft back.

The wings of a glider have a set of controls called ailerons. Some gliders are equipped with an additional set of controls called flaps. Ailerons and flaps are hinged panels located along the trailing edge (rear) of the wings. The ailerons are close to the tip of the wing, whereas, the flaps are nearer to the body of the glider. The glider pilot moves the ailerons up or down which causes the glider to turn either left or right. This maneuver is accomplished because as the pilot raises one aileron, the other is automatically lowered causing the glider to tilt in the direction that the air current is lifting the raised wing. If the glider is equipped with flaps, the pilot is able to increase lift at low speeds when flying in an updraft by lowering a flap which allows the air current to raise the glider upward. Maneuvering the flap allows the pilot to control the angle of the lift in relation to the speed of the air current.

The body of the glider is known as the fuselage. It extends from the nose of the glider to the tail end of the aircraft and gradually narrows towards the rear. The fuselage is made up of materials that can be sanded to a smooth finish. These materials include wood, aluminum or fiber glass. A glider may also include some parts made from steel. The landing gear of most gliders can be folded into the body after take-off which provides the aircraft with a smooth undersurface and eliminates extended parts which would increase drag.

The tail assembly is known as the empennage. The empennage consist of a vertical fin, rudder, a horizontal stabilizer and an elevator. The elevator is hinged to the stabilizer and is raised or lowered by the pilot by means of a control stick in the cockpit. By positioning the elevator, the pilot can tilt the plane to a desired angle to help control the glider's speed. The rudder can be moved to the right or left via manipulation of pedals in the cockpit by the pilot. The rudder helps to control the glider during a turn.

(C) LAUNCHING A GLIDER

A glider can be launched into the air in one of three basic ways: towing it up behind an airplane; pulling it up like a kite by means of a cable and winch, or placing a small engine in the glider for unassisted take-off.

Most gliders use the method of being towed into the air via an airplane. The plane pulls the glider with a rope about two hundred feet long or sixty-one meters in length. The rope is connected to a tow hook near the tail wheel of the plane, and to a similar hook fastened to the nose of the glider. The rope can be released from the nose of the plane via a knob in the cockpit. The glider pilot generally releases the rope when the aircraft reaches an altitude between two and three thousand feet (six hundred and ten to nine hundred and ten meters).

For a winch launch, the glider is attached via a cable to a hauling device called a winch that stays on the ground. The winch pulls the glider along the ground until it reaches a speed of about sixty miles per hour. Once it reaches this speed, wing lift is generated for the aircraft to leave the ground and begin its steep climb into the air. When the glider reaches about two hundred feet, the pilot levels his plane out and releases the launch cable via a device in the cockpit.

Some gliders are equipped with an engine-driven propeller that is used for take-off. Once the craft is airborne, the pilot turns the engine off and begins the flight.

(D) HOW GLIDERS FLY

Although some gliders utilize engines for take-off, all gliders maintain flight through the manipulation of air currents. There are basically two ways that air currents are utilized to maintain a glider's flight once takeoff is achieved. Hill lift and thermal convection are the two forms of upward moving air currents which aid a glider in maintaining flight. Hill lift was first discovered and utilized by Otto Lilienthal more than seventy five years ago (24). Lilienthal discovered that when wind blows against a hill, the air moves upward against the slope of a hill. This principle governing air movement became critical in the early 1920's. It was during that time when pilots discovered that height could be maintained for longer periods of time by flying along a hillside as compared to flying away from a hill.

The use of thermal convection in gliding was discovered in 1928 by an Austrian scientist, Robert Kronfeld (25). First Kronfeld discovered that warm updrafts of air produced certain types of clouds called cumulus clouds. Warm air rises because it is lighter than cool air. This rising body of warm air is called a thermal.

Although thermals are invisible, they can be detected by pilots because of the type of cloud patterns they produce. Once a pilot detects cumulonimbus clouds, he uses it to lift the glider upward until it reaches the top of the warm current. The gilder will then descend in search for the next warm updraft or thermal. When the glider is raised by these thermals or warm updraft it does so in ascending spirals. (See Figure 3 at the end of this section). In addition to visually detecting thermals through cloud patterns, most pilots rely on two different types of instruments to detect thermals—a variometer and an altimer. A variometer is a very sensitive instrument which measures how fast a glider is gaining or losing height and the altimer records the height of the aircraft above the ground. These two instruments aid pilots in determining the thermals' ascending effect upon the glider and descending effect when the glider has left the the thermal.

FIGUREIII How Gliders Fly
(figure available in print form)

LESSON PLAN IV

I. OBJECTIVE:

(1) The student will make a glider.

II. NOTE TO THE INSTRUCTOR:

For the best possible results from your students gliders, have them to make the gliders out of balsa wood. Balsa wood can be purchased at any hobbie and craft shop, or art supply store.

III. MATERIALS NEEDED:

(1) balsa wood or poster board

(2) modeling knife

(3) airplane glue

(4) steel ruler

(5) tacks

IV. PROCEDURES:

(1) Have the student cut the fuselage in the following dimensions from balsa wood: 6” x 1/4” x 1/8”. (Some craft stores will cut a board this size for you.)

(2) Have the students cut out the wings from the flat sheet of balsa wood 8” x 1 1/2” x 1/16”. Place the wing on the fuselage 1 1/2 inches from the front. Make sure that the wing is centered. Then nail down the wing at that location.

(3) Have the student cut the tail of the glider in the following dimensions: 3 1/2” x 1/2” x 1/16”. Place it at the end of the fuselage and glue

(4) Have the student cut the rudder from the sheet of balsa wood in the following dimensions: 1 1/2” x 1” x 1/2”. Place the rudder standing vertically in front of the tail and glue.

(5) If you wish you can have the students make elevators and hinge them onto the tail. Should you decide to do this, make them in the following dimensions: 3 1/2” x 1/2” x 1/16”.

Notes

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