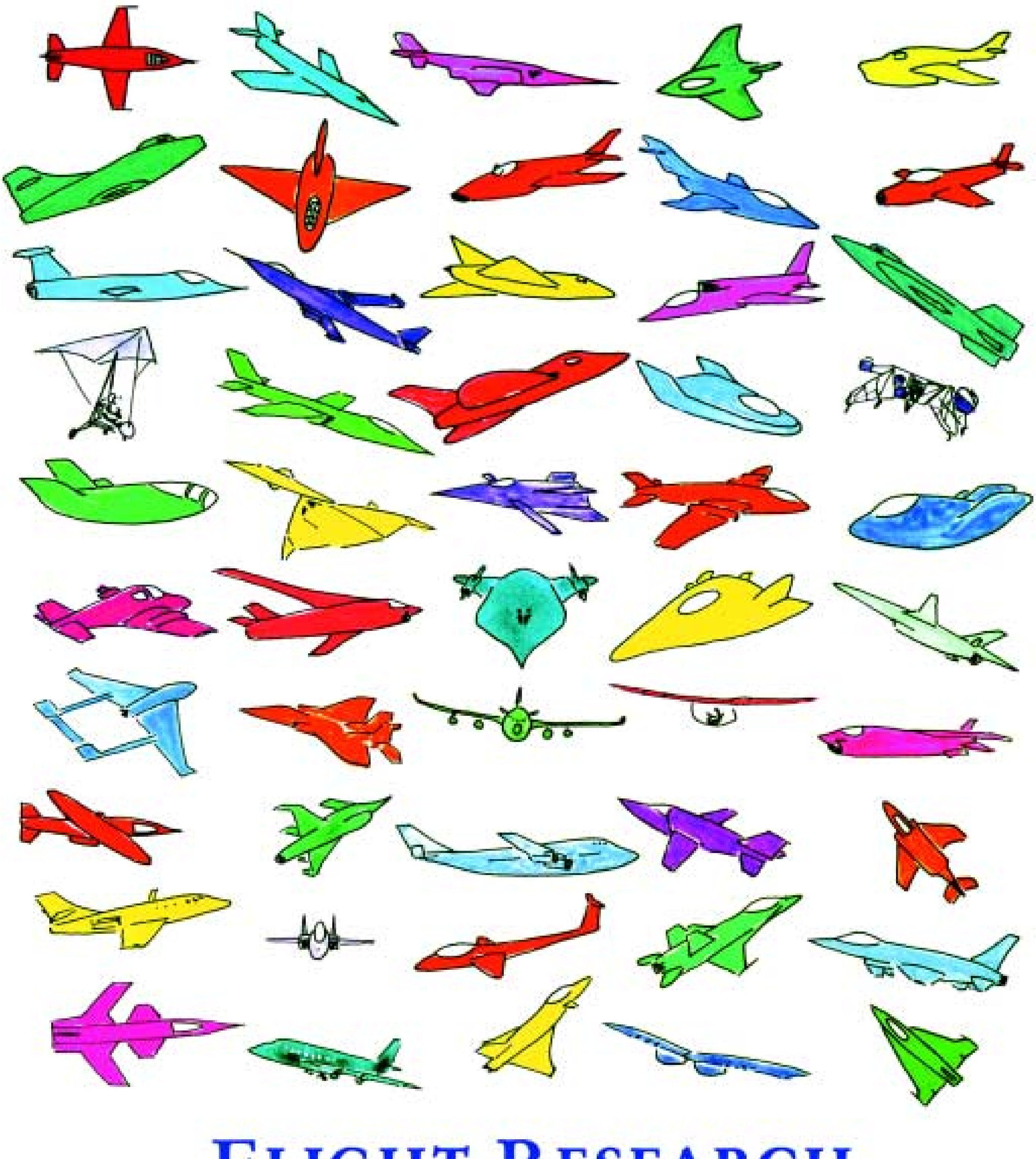
Tools of the Trade



Flight Research

NASA Aerospace Technology Enterprise

Aircraft as Research Tools

Aeronautical research usually begins with computers, wind tunnels, and flight simulators, but eventually the theories must fly. This is when flight research begins, and aircraft are the primary tools of the trade.

Flight research involves doing precision maneuvers in either a specially built experimental aircraft or an existing production airplane that has been modified. For example, the AD-1 was a unique airplane made only for flight research, while the NASA F-18 High Alpha Research Vehicle (HARV) was a standard fighter aircraft that was transformed into a one-of-a-kind aircraft as it was fitted with new propulsion systems, flight controls, and scientific equipment. All research aircraft are able to perform scientific experiments because of the onboard instruments that record data about its systems, aerodynamics, and the outside environment.

NASA pilots work closely with engineers to conduct a meticulous flight program that gradually probes an aircraft's capabilities: edging toward the speed, altitude, and structural limits that will define the final performance of an aircraft or concept. This procedure furnishes answers that will verify, extend, and perhaps correct the inputs from computer studies, wind tunnel tests, and simulations. It is the last step in the development process and leads the way for designs that can be put into production. It also delivers the final word on a most crucial question: How well does it fly?

The X-5 for instance, showed that an aircraft can be flown with moveable wings that can be swept back in flight, a concept that was later used in many airplanes, such as the F-111, F-14, and B-1. However, the X-3 demonstrated that while some of the concepts in its design were successful (short wings), the combination of short wings, small tail, and long fuselage did not fly well; aircraft designers took note, and avoided the X-3's problems on subsequent short-winged aircraft.

Experimental research aircraft are tools of exploration, incorporating the newest ideas in every aspect of aerospace flight, so for this reason they come in many shapes and sizes. Some have short wings, delta wings, swept wings, movable wings, and no wings. They fly with jet engines, rocket engines, piston engines, solar-electric engines, and even no engines. Some research planes are too small to carry a pilot, while others are as big as airliners. And no matter how radical they seem at first, they contribute to what is eventually considered conventional.

The first experimental planes designed exclusively for research were the XS-1 and the D-558-1. They were made in 1946 to enable scientists and pilots to study flight near the speed of sound. Custom-made airplanes were the only means to accomplish this research because supersonic wind tunnels at the time were not accurate enough, and no other airplanes had flown that fast. The supersonic era began when the XS-1 broke the "sound barrier" in 1947.

In the 1950's the famous "X-Planes" continued to take people to higher altitudes and greater speeds. They were the first aircraft to fly Mach 2 and Mach 3, and the studies done with them influenced the designs of all supersonic planes.

In the early 1960's, the X-15 rocket plane became the first aircraft to fly into space. It was one of many aeronautics projects that supported NASA's Apollo Lunar Landing Program, but the X-15 was so advanced that it also benefited the Space Shuttle nearly 15 years later.

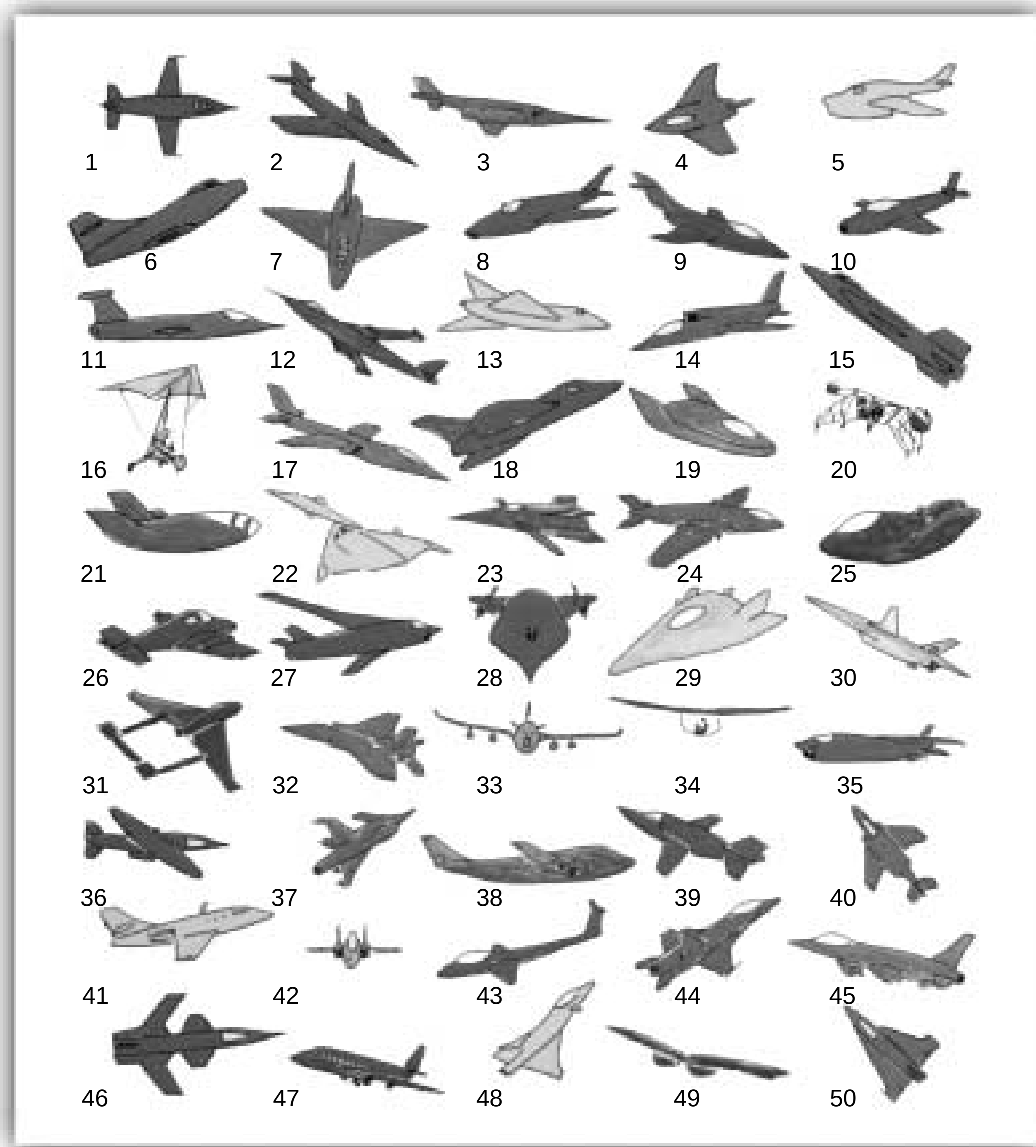
Since the 1970's, NASA flight research has become more comprehensive, with flights involving everything from Space Shuttles to ultralights. NASA now flies not only the fastest airplanes, but some of the slowest. Flying machines continue to evolve with new wing designs, propulsion systems, and flight controls. As always, a look at today's experimental research aircraft is a preview of the future.

Aero-Space Technology Enterprise

The NASA Aero-Space Technology Enterprise (AT) is one of the four NASA Strategic Enterprises established to address key agency activities in distinctly different areas. The Aero-Space Technology Enterprise's work in science and technology is aimed at sustaining U.S. leadership in civil aeronautics and space transportation. For over 75 years, NASA and its predecessor, the National Advisory Committee for Aeronautics, have worked closely with U.S. industry, universities, and other Federal agencies to give the U.S. a preeminent position in aeronautics. NASA has expanded this relationship to include aerospace companies, and is now working to revolutionize America's space launch capabilities.

NASA Aero-Space Technology Home Page

http://www.aero-space.nasa.gov/



Tools of the Trade: Research Aircraft

The front of this poster represents a selection of research aircraft flown by NASA and its predecessor, the National Advisory Committee for Aeronautics (NACA). The research aircraft program began in 1946, and has flown the world's most advanced experimental aircraft in research programs developing the newest concepts in aeronautics. These unique flight vehicles have influenced the entire spectrum of military and commercial aviation; from hypersonic rocket planes and solar-powered ultralights, to Space Shuttles and airliners. The following list describes research programs during the last half of the Twentieth Century. The numbers correspond to the key above.

1946-1956

1. **XS-1**: Experimental research rocket plane, successfully designed to break the "sound barrier" and study supersonic flight.
2. **X-2**: Swept-wing, rocket-powered aircraft; first to achieve Mach 3.
3. **X-3**: Experimental jet explored flying qualities of low aspect ratio (short) wings.
4. **X-4**: Small, experimental jet used to study semi-tailless aircraft at transonic (near supersonic) speeds.
5. **X-5**: Experimental jet; first to verify the concept of moveable wings that can be swept back while in flight.
6. **D-558-1**: Experimental jet; developed with the XS-1 to provide some of the first in-flight data on transonic flight.
7. **XF-92A**: Experimental fighter prototype was America's first delta-wing (triangular wing) jet.
8. **F-100A**: Production fighter jet used in research program that lead to design improvements which solved aircraft's dangerous instability problems (inertial coupling).
9. **F-101A**: Production fighter used in NACA performance evaluation tests of new armed service aircraft of the 1950s
10. **YF-84A**: Prototype jet fighter flown to evaluate the use of "vortex generators" to control airflow over the wings.

1956-1966

11. **YF-104A**: Jet fighter used to develop "reaction controls," which are small thrusters used for flight control in the upper atmosphere and space.

12. **B-47A**: Early jet bomber flown by NACA to study and improve the design of aircraft with large, swept-back wings.

13. **YF-102A**: Fighter version of XF-92A used to continue delta wing research.

14. **YF-107A**: Fighter prototype used in research program to develop the first "sidestick" flight control system.

15. **X-15**: First aircraft capable of hypersonic (Mach 5+) flight into space.

16. **Paresev 1-A**: Experimental flight vehicle; first to develop flexible, "parawing" glider concept.

17. **A-5A**: Bomber used in flight program to determine air traffic system procedures for future supersonic transport (SST).

18. **F5D-1**: Navy fighter prototype flown in SST landing and approach studies.

19. **M2-F2**: Wingless, experimental research aircraft; first high-speed, "lifting body" flight vehicle that generated lift from its body shape instead of wings.

20. **LLRV**: Experimental Lunar Landing Research Vehicle (LLRV) simulated lunar spacecraft landings; derivatives became the in-flight trainers used by Apollo astronauts.

1966-1976

21. **HL-10**: Experimental lifting body; evaluated "inverted airfoil" body shape for wingless flight vehicles.

22. **XB-70A**: Experimental Mach 3 bomber used to study flight characteristics of large, supersonic aircraft.

23. **Hyper III**: Remotely-piloted experimental aircraft flown to investigate the use of small, deployable wings for increasing glide range of lifting body designs.

24. **B-57B**: Medium bomber modified for research program to study aviation weather such as clear air turbulence and mountain wave.

25. **X-24A:** Experimental research aircraft designed to investigate the teardrop lifting body shape for a space vehicle.

26. **PA-30-160B**: Production airplane modified to develop remotely-piloted aircraft systems.

27. **F-8A SCW**: Fighter modified with experimental, supercritical wing (SCW) to improve transonic performance.

28. **YF-12A**: High-speed reconnaissance aircraft modified for research and development of navigation and engine systems on Mach 3 aircraft.

29. **X-24B**: Lifting body research aircraft; as the first lifting body to land on a conventional runway it proved the feasibility of accurate, unpowered Space Shuttle landings.

30. **Firebee**: Remotely-piloted aircraft modified for aerodynamic and structural testing.

1976-1986

31. **Mini-Sniffer III**: Remotely-piloted research vehicle (RPRV); designed to gather air samples at altitudes of 30,000 m (98,000 ft.), in support of research determining the effects of jet aircraft exhaust in the upper atmosphere.

32. **F-15 SRV**: 3/8-scale, F-15 RPRV used as a Spin Research Vehicle (SRV) to evaluate spin characteristics of the F-15 fighter.

33. **KC-135A**: Modified air tanker; first transport-size aircraft to use "winglet" wingtip extensions to decrease drag and improve aircraft performance.

34. **Gossamer Albatross**: Human-powered aircraft used by NASA to evaluate aerodynamics of large, light weight aircraft.

35. **F-8B DFBW**: Fighter modified to develop the first digital fly-by-wire (DFBW) flight control system.

36. **AD-1**: Experimental "swing-wing" Ames-Dryden (AD) research aircraft flown to evaluate concept of wings that sweep forward and backward in flight.

37. **HiMat**: Experimental RPRV used to develop Highly Maneuverable Aircraft Technology (HiMat); design incorporated composites, canards and winglets.

38. **B-747 SCA:** Airliner modified to serve as Shuttle Carrier Aircraft (SCA); used to ferry Space Shuttles.

39. **F-111 MAW**: F-111 fighter/bomber modified with a Mission Adaptive Wing (MAW) that changes shape for flight control, instead of using flaps and ailerons.

40. **F-4C**: Fighter modified for wing aerodynamics research.

1986-1999

41. **Jetstar**: Business jet modified as in-flight simulator to duplicate flight characteristics of various aircraft.

42. **F-15 FRA**: Fighter modified for research, Flight Research Aircraft (FRA) was a testbed for new technologies including integrated propulsion/flight controls.

43. **PIK-20E**: Production sailplane used to establish procedures for collecting sailplane glide performance data.

44. **F-18 HARV**: Fighter modified for high angle of attack (extreme nose attitude, or alpha) flight and research; High Alpha Research Vehicle (HARV) was flown with and without the use of vectored thrust.

45. **F-16 AFTI**: Fighter modified for use in Advanced Fighter Technology Integration (AFTI) research program; voice-actuated controls, digital flight control system and other advanced technologies evaluated for future fighter aircraft.

46. **X-29:** Experimental research aircraft incorporated many new technologies, including forward-swept wings of composite construction, canards, and triple-redundant DFBW flight control system.

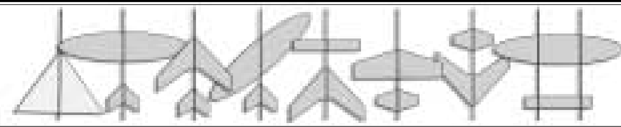
47. **CV-990 LSRA**: Airliner modified as Landing Systems Research Aircraft (LSRA); it was used to test Space Shuttle landing gear systems.

48. **X-31**: Experimental research aircraft featured vectored thrust, and was designed to evaluate technologies that enhance fighter maneuverability.

49. **Pathfinder**: Experimental solar-powered flying wing used to develop technologies for future aircraft capable of high-altitude flights, lasting several days in duration, for environmental research.

50. **F-16XL**: Prototype fighter modified to research technologies which significantly decrease wing drag at supersonic speeds.

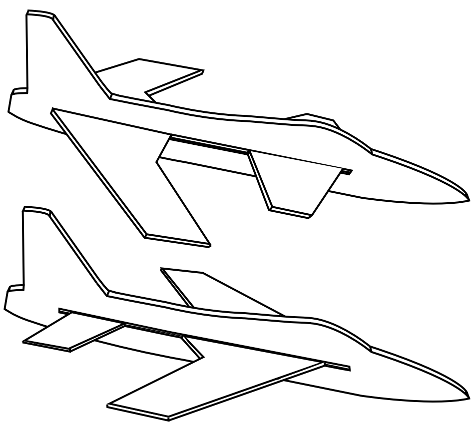
X-GLIDERS



Objectives

The students will:
Build a glider.
Learn how to change the flight characteristics of a glider.
Conduct an experiment to answer a question.

Standards and Skills

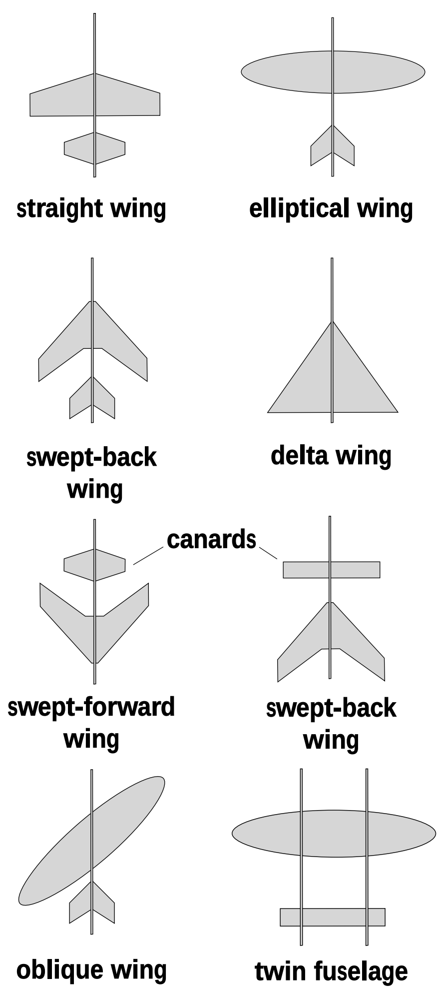


Science
Science as Inquiry
Physical Science
Science and Technology

Mathematics
Measurement
Problem Solving

Science Process Skills
Making Models
Investigating
Predicting

Background



The most obvious features of the airplanes on the cover of this poster are the various wing shapes. The top row of airplanes depicts the first experimental research aircraft (“X-planes”) flown for the NACA, and each used different wing and tail configurations to tackle the problems of supersonic flight.

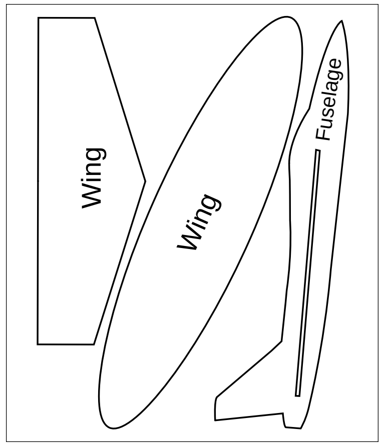
These early jet aircraft had straight wings (X-1), wings that angled (swept) toward the tail (X-2), triangular (delta) wings (XF-92), and wings that could be moved in flight to change the angle of backward sweep (X-5). Each design added to our knowledge of high-speed flight. More recently, aircraft designs have incorporated wings that sweep forward (X-29), and even wings that sweep forward and backward at the same time (AD-1 oblique wing aircraft). The X-29 and the X-31 also made use of small wing-like control surfaces called canards which are located ahead of the main wings.

The templates on this poster allow educators and students to build and experiment with all of these basic wing/tail/canard configurations. Eight different plastic foam “X-gliders” can be built using these templates (see illustrations, left), but the total number of variations is only limited by the imagination of the “designer.”

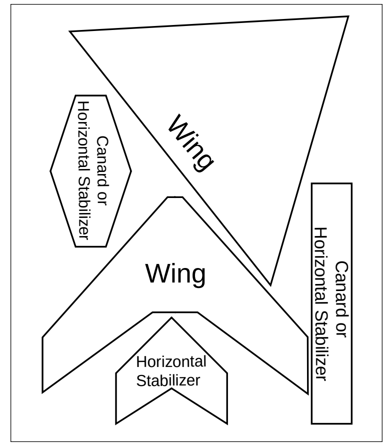
Materials for building airplanes must be lightweight, strong, and readily available. These qualities make plastic foam a good material for the construction of flying models. Introduce the X-Glider Activity by discussing with the students some reasons for using plastic foam in the construction of a model glider. Most real airplanes are made from another lightweight, strong, and readily available material called aluminum.

Materials

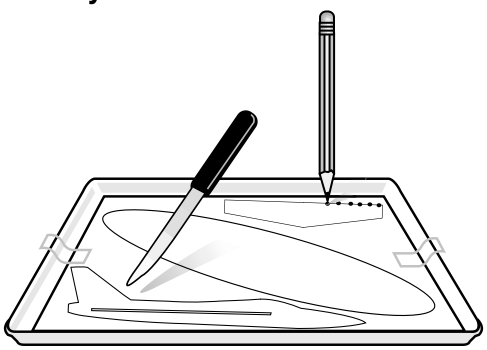
Plastic foam food tray,
 about 28 cm X 23 cm (Size 12)
Cellophane tape
Paper clips
Binder clips
Ball point pen
Plastic knife or scissors
Toothpicks
Goggles (eye protection)
Emery boards or sandpaper

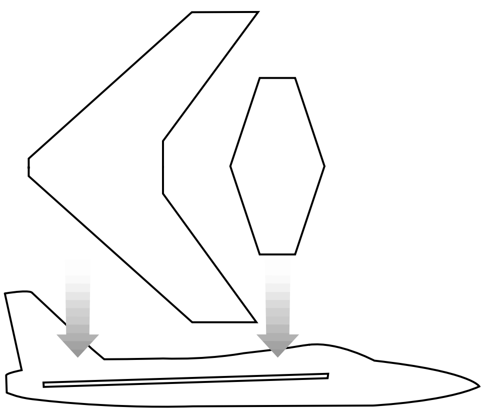


Template keys



Activity





1. Provide the student with a word list for parts of the glider: *fuselage, wing horizontal stabilizer, canard* (see template keys above).

2. Distribute plastic foam trays and copies of the X-glider templates.

3. Ask the student to write the name of each airplane part on the template.

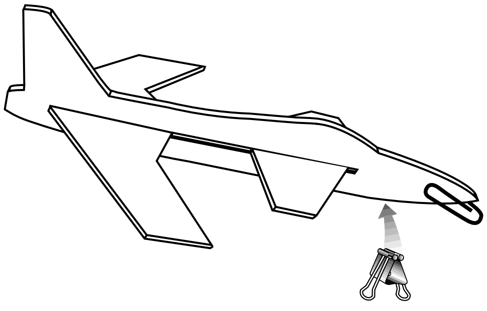
4. Tape the glider template to the food tray.

5. Cut out the airplane parts using the templates. Plastic foam can be cut using scissors, a razor knife, or a serrated plastic knife. It can also be cut using a sharp pencil or round toothpick to punch a series of holes approximately 2mm apart around the outside edge of the part. The part can then be pushed out from the tray. Educators of K-2 students may want to cut out the glider parts ahead of time.

6. If there are any rough edges around a part, they can be smoothed using sandpaper or an emery board.

7. Carefully cut a slot in the fuselage. Slide other parts into it to finish the glider (refer to the X-glider silhouettes for the basic designs; another fuselage is needed to make the “twin fuselage” glider.)

Extensions

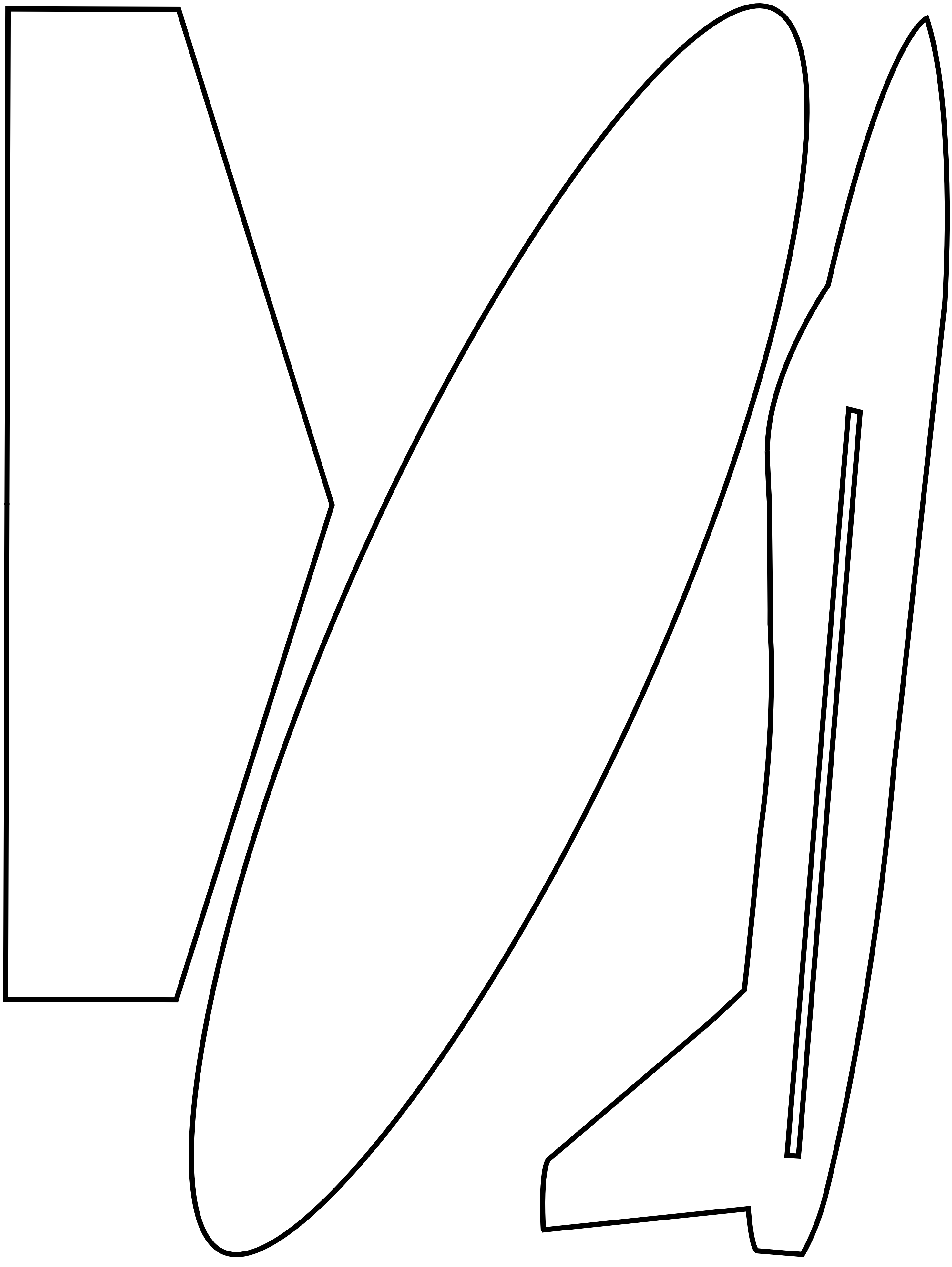


1. An airplane’s weight must be properly balanced for it to fly safely. The same "weight and balance" principles apply to models. The students can determine the proper weight and balance by attaching a paper clip or binder clip to the fuselage. Students should vary the position of the clip with each flight until the glider flies the greatest distance in a straight line. Additional clips might be needed to improve the glider’s flight performance.

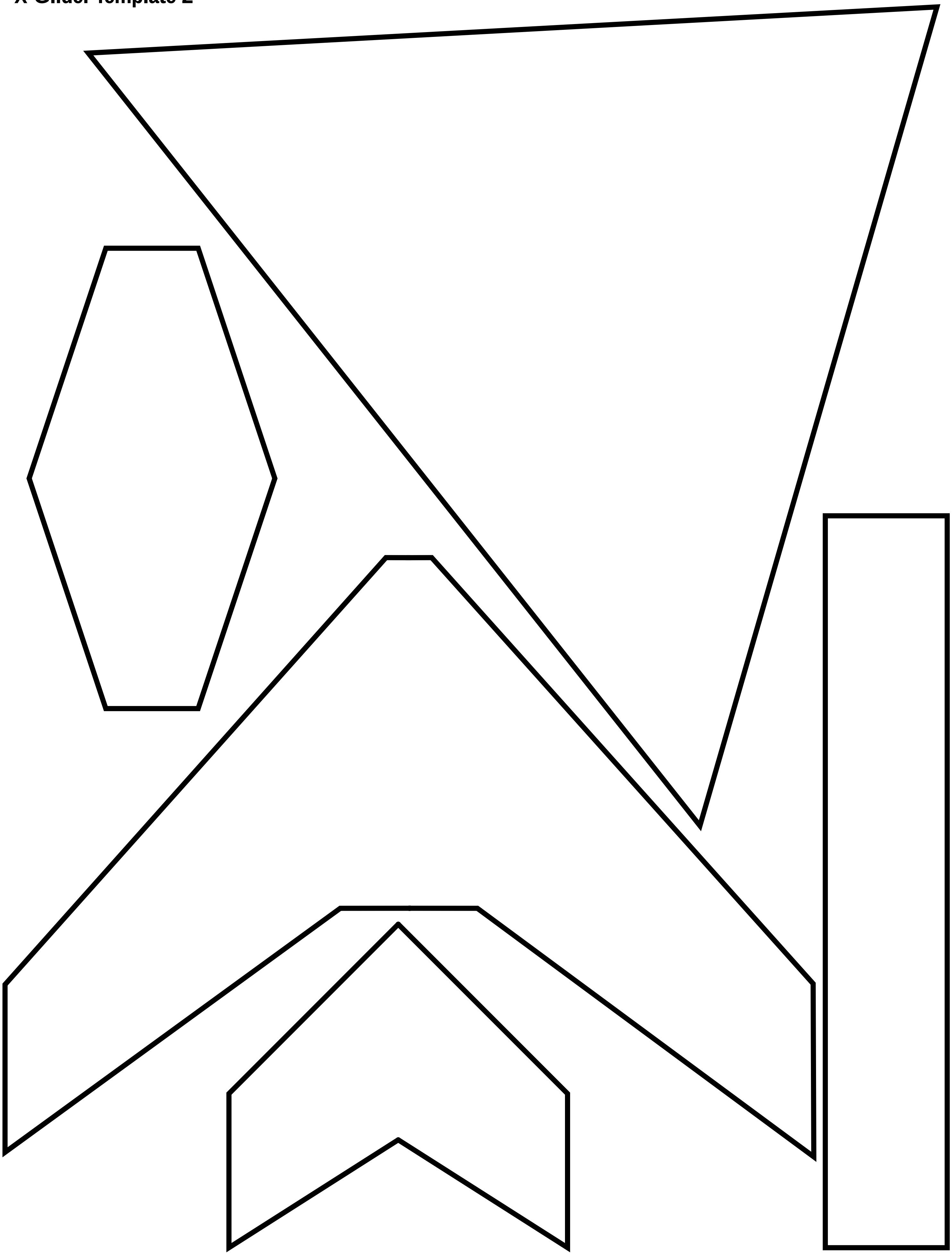
2. Weight and balance is also determined by the position of the wings, canards, and other surfaces along the fuselage. Have the students move the wings, stabilizers, and canards to different positions in the fuselage to determine the settings that make the glider fly best.

3. Have students measure and record the distance of each flight, and compare the results with each change in the glider’s weight and balance.

X-Glider Template 1



X-Glider Template 2



Basic Aeronautical Terms and Definitions

airfoil: An aerodynamic surface shaped to obtain a reaction from the air through which it moves; for example, wing, rudder, aileron, or rotor blade.

aerodynamics: The branch of science that deals with the motion of air and the forces on bodies moving through the air.

aeronautics: Word derived from the Greek words for “air” and “to sail.” It is the study of flight and the operation of aircraft.

ailerons: Moveable control surfaces forming part of the trailing edge of the wing that are used to make the airplane roll and bank.

canard: An horizontal stabilizer placed ahead of the wing.

drag: Anything that slows or disrupts the airflow over an airplane, slowing the plane and opposing thrust.

elevator: A moveable control surface usually attached to the horizontal stabilizer on the tail that is used to control pitch (changing the attitude of the aircraft’s nose, making it move “up” or “down.”)

flight controls: Moveable surfaces on the aircraft that control its path through the air. The most typical control surfaces are ailerons, rudders, and elevators.

fuselage: The main structural body of an aircraft to which the wings, tail unit, etc. are attached.

horizontal stabilizer: Usually a fixed, horizontal tail surface, but some are designed to move like an elevator.

hypersonic: Speeds of Mach 5 and greater.

lift: The sum of all the aerodynamic forces acting on an aircraft at right angles to the flight path. Wings create lift.

lifting body: An aircraft that uses the shape of its body to generate lift instead of using wings.

Mach number: Speed in terms of the speed of sound, i.e. Mach 1 is the speed of sound.

mountain wave: Wavelike airflow produced on the downwind side of a mountain as a result of steady, strong winds blowing over the mountain top.

parawing: A flexible, fabric wing that uses the air pressure beneath it to form an airfoil that generates lift.

production aircraft: An aircraft type produced in quantity.

prototype aircraft: A pre-production aircraft suitable for complete evaluation of its operating systems and performance.

rudder: A moveable control surface used to provide yaw (sideways movement), it is usually part of the vertical stabilizer on an aircraft’s tail.

sailplane: A high-performance glider.

solar-powered aircraft: An aircraft using photovoltaic cells to convert energy from the sun into electricity to power electric motors that drive the aircraft.

sound barrier: A nonscientific term referring to the effects of air pressure upon an aircraft as it attains the speed of sound. Once believed to be an aerodynamic “barrier” preventing controlled, supersonic airplane flight.

straight-wing: A wing that is perpendicular to the fuselage.

supercritical wing: A NASA-developed airfoil design that has relatively low drag at speeds near the speed of sound.

supersonic: Faster than the speed of sound (about 750 mph at sea level).

swept-wing: A wing that has a visibly obvious backward or forward inclination relative to the fuselage.

thrust: A force that propels an aircraft forward.

transonic: Speeds slightly above and below the speed of sound.

ultralight: A piloted flight vehicle that weighs less than 140 kg (empty).

vectored thrust: Engine exhaust flow (thrust) that is directed at angles relative to the aircraft’s fuselage. Thrust vectoring improves aircraft maneuverability.

vertical stabilizer: A vertical or inclined airfoil, usually at the aircraft tail or wing tip designed to increase the aircraft’s directional stability (keep the aircraft moving “straight ahead”).

Poster credits:
Design, illustration, and text by Ted Huetter.
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Additional graphics support by Steve Lighthill and Rod Waid.

On-Line Educational Resources

NASA Education Home Page
The NASA Education Home Page serves as a cyber-gateway to information regarding educational programs and services offered by NASA for educators and students across the United States. This high-level directory of information provides specific details and points of contact for all of NASA's educational efforts, NASA field center offices, and NASA Regional Educator Resource Centers located in all 50 States and Puerto Rico.

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NASA Education Home Page:
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NASA's Learning Technologies Project (LTP) is an agency asset that includes a suite of Internet projects that teachers and students can use to explore NASA resources and learn about NASA missions.

LTP offers a wide variety of educationally sound, standards-based projects that help educators explore science, math, and engineering from the classroom. LTP also supplies information on integrating technology into the classroom, and on grant opportunities.

Through "Sharing NASA" (interactive projects available from LTP's Quest server) and the Learning Technologies Channel (LTC) educators and students can participate in events via a multidimensional web experience. E-mail, chat rooms, audio, video, text transcription, and sometimes NASA Television are employed to take participants to workshops, lectures, seminars, courses, and exciting live events around the world.

LTP Home Page:
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For Learning Technologies Channel information, e-mail:
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NASA Glenn Research Center
http://www.grc.nasa.gov/Doc/educatn.htm
NASA Marshall Space Flight Center
http://www1.msfc.nasa.gov/education/

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NASA Dryden Flight Research Center Gallery offers photographs and movies depicting NACA and NASA research aircraft including each airplane on this poster.
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