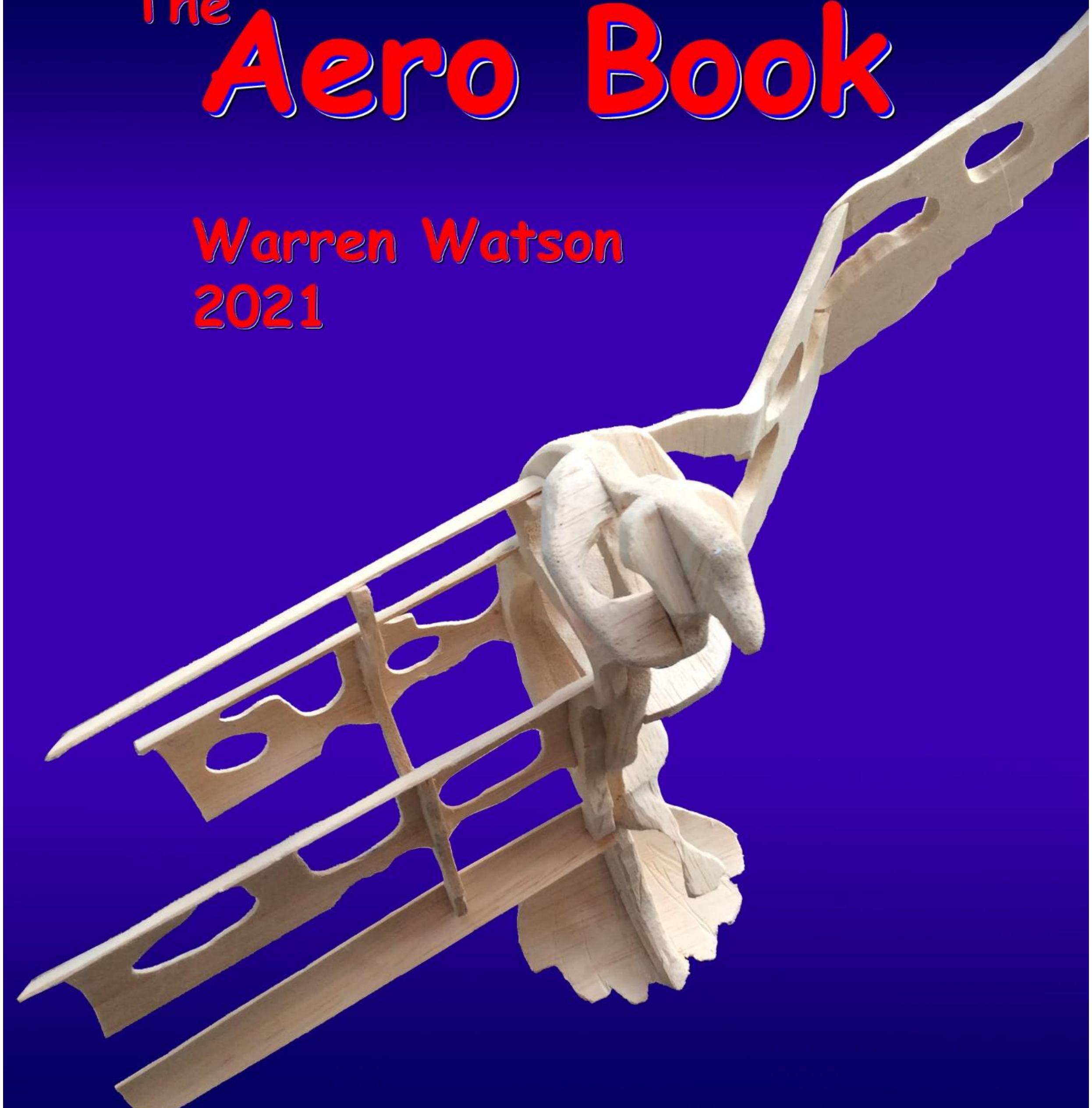
The Aero Book

Warren Watson
2021



The Art and Science of Building a Model Airplane

The Aero Book

The Art and Science of
Building a Model Airplane

by Warren Thorpe Watson
Honours BASc in Engineering Physics
MASc in Aerodynamics
Diploma in Fine Arts

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Preface

"Once you have tasted flight,
you will forever walk the earth with your eyes turned skyward,
for there, you have been,
and there, you will always long to return." Many attribute this to Leonardo

In a Star Trek movie, the undiscovered country was the future[1]. That may be true, but the mind is so much so the undiscovered country as well. Learning is a lot of fun, and the natural world like birds in flight provide so much to wonder about. This book explores the link between science and art as well as providing an overview of aerodynamics.

The front cover is half bird and half biplane. Man looked to the birds much before being able to fly himself. He then explored being airborne with kites, balloons, models, and then manned aircraft (a/c).

This book covers a project designed for first-year engineering students at Queen's University in Kingston, Ontario. The project was entitled, "If Loons can Fly, then So can Loonies[2]." The goal of the project was the design of a balsa wood rubber-powered propeller model airplane to carry asymmetrically placed loonies. A lesser goal was to takeoff and to land with one symmetrically placed loonie.

This book will satiate the desire for knowledge in the process of flight through kites, paper airplanes and a balsa wood airplane as well as some exploration of the natural world. It is the curiosity of the natural world that first led to flight.

About the Author

Warren Watson is an engineer, a writer, an artist, and a bridge manager/instructor. He has an honours BASc in Engineering Physics from the University of British Columbia in Vancouver, BC and a MASc in Aeronautical Engineering from the University of Toronto Institute for Aerospace Studies (UTIAS). He also has a diploma in Fine Arts from Okanagan University College in Kelowna, BC.

He has always been interested in everything even as a youth. His continual questions must have driven his parents nuts. He had an extremely active mind. One of his lasting memories was watching a superhero on television when his mother changed the channel to watch the moon landing of July 20, 1969.

He has a love for literature and science. In the first year of university, he belonged to the Pre-Med club. He excelled at math, physics and biology and went into engineering. He wore a NASA patch on his engineering red jacket. Being an astronaut was certainly a castle in the sky especially since he became queasy in boats and on carnival rides.

During flying lessons, he never had a problem when his hand was on the control stick, and he could feel how the aircraft moved. He had no problem on a boat if he were doing the sailing. However, there were no astronauts with a faulty depth of vision. Regardless, part of the fun with any castle in the sky is the building of a foundation under it.

This process led him into aerodynamics and the design of passenger aircraft like the de Havilland Dash 8-400Q, the IPTN N250, and the Bombardier Canadair Regional Jet and Global Express. IPTN is Indonesia's national aircraft manufacturer in Bandung, West Java. The acronym stands for Industri Pesawat Terbang Nusantara. Pesawat means airplane, terbang means fly and nusantara means archipelago[3]. The N250 is a high-wing commuter aircraft like the Dash 8-400Q. Specifically, his design work was on the armpit of the wing or the wing root fairing covering the joint of the wing with the fuselage.

Taking pilot lessons was only natural. He had many hours of instruction in a Cessna 172 (high wing small airplane) and a Piper Warrior (low wing small airplane). He did many touch-and-goes, wingovers and spins before failing the medical exam. Despite what the doctor said, the love of any type of flight was the real diagnosis.

He always wanted to write an aerodynamics book for the layman and the modeler. Building a castle in the sky like being an astronaut is not a problem even if it is an unattainable goal. The fun and the success come from building a foundation under it and seeing where that leads.

Recommendations

"The Aero Book is a very well-done book and very appropriate for students at the senior high school level. It is really well presented." Dick Hamakawa.

Dick, born in Vancouver, BC in 1936, is a veteran and a former schoolteacher. He was in the Artillery and the RCAF for seven years. He taught Science, Physics and Math in Toronto, Ontario and in the British Columbian cities of Burnaby, Port Hardy, Terrace and Nelson. He was a pilot and flew tail draggers such as the Beechcraft D18S Expeditor, Fleet 80 Canuck, and Cessna 140[4].

"Kitty Hawk is the Mecca of aviation-oriented people, me included. I would be happy to recommend the book as a treatise on the mechanics of flight." Charles Bennett.

Charlie was born in Kentucky in 1946. He was an airline operations agent and air traffic controller and worked for the FAA (US Federal Aviation Authority) for thirty-one years. He worked in several places including Alaska and the San Francisco Bay area and currently resides in Spokane, WA. In his later career, he worked for private corporations implementing, testing, and designing advanced Air Traffic Control systems. Charlie is an avid bridge player, director, and club manager. He directs bridge players, not aircraft[5].

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1. Looking to the Sky

It is easy to get enjoyment from the natural world. Many people who become interested in flight walk into potholes. They like looking to the sky.

1.1 Birds

1.1.1 Watching Birds

Is watching birds for the birds? No of course not. Hours of entertainment can be achieved by watching them. The above picture was taken on the car ferry from Port Bolivar to Galveston, Texas. It is even better watching a fellow tourist feeding them on the car ferry trip from Ocracoke to Cedar Island in the North Carolina Outer Banks. This is a good detour after a visit to Kitty Hawk.

In the following triptych, a seabird comes in with wings flared to pick a piece of bread out of the outstretched arm of a nameless tourist.

1.1.2 Wing Shape Adjustment

An early method of aircraft control was wing warping. Birds can change the shape of the wing, and the rear feathers even come down like landing flaps to increase the area of the wing for more lift. Birds have little muscles to do this[6]. Birds also have feedback feathers that aid in flight called filoplumes. They help determine if the wing area should be small or large.

1.1.3 Birds Fly in a Vee

The one thing that everybody knows about birds is that they migrate in vee formation. Birds fly in a vee because it is easier that way. A bird's wing is kept in the air because of high pressure below and lower pressure above the wing. At the wingtip, air from below tries to roll over on top of the wing creating trailing vortices. A bird is just flying in the uplift of the vortex produced by the bird in front of it.

Ehrlich of Stanford University[7] believes that the vee formation helps the birds fly in an orderly formation to avoid collisions. This may be true but getting help from the uplift of the bird in front is not like drafting. The bird does not need to tailgate to feel the effect of the vortices.

It has been explained why birds fly in a vee, but why is one side of the vee longer than the other? There are more birds in it. :-)

1.1.4 Ground Effect

When a bird or an airplane is flying close to a surface, it gets some help in lift. Ehrlich states a bird must be much closer than a wingspan from the surface. This is usually only possible over water where birds can skim the surface[8]. The one thing guaranteed is that a bird has not read an aerodynamics text, it is just flying where flight is easier. Ground effect is studied in the design of wing-in-ground-effect (WIG) vehicles that travel close to the surface of water[9].

1.1.5 Built for Flight

In additional to flying where flight is easy, birds have several characteristics that help them fly[10]. They have hollow bones and feathers. Feathers are not hollow just so humans can have a quill pen. They are hollow for lightness.

Birds also have an exceptional respiration system. The flow is unidirectional through hollow bones, air sacs and lungs. This way there are no dead air spaces, and the lungs are optimized. Birds normally fly below 500 feet except to migrate. A good testament to a bird's respiratory system is provided by the Whooper swan. Such a bird has been seen at 29,000 feet[11], perhaps enjoying a Jetstream. If the aircraft is not pressurized, human passengers need oxygen at 15,000 feet (CFR or FAR 91.211[12]). Whooper swans apparently cannot read the US Code of Federal Regulations, also known as the Federal Aviation Regulations.

A good respiratory system would be pointless if the heart were not strong. The muscles for flight are well supplied with blood vessels and tend to be the dark meat.

Weight is saved by hollow bones and feathers but is also saved because birds do not carry any waste. There is no bladder. Waste is dropped as it is produced, usually on the head of a well-dressed human.

Ehrlich states that a bird's vision and brain are suited for highspeed decisions during flight. Mother Nature is an exceptional design engineer.

1.1.6 Migration and Soaring

Bird migration is a spectacular feat of nature. Shorebirds migrate between their wintering spots in South and Central America to their summering spots in the North, even the Arctic. Shorebirds may even migrate as high as 10,000 feet at speeds approaching the 55-mph speed limit[13].

Why do birds increase their height with time of migration? They find it easier to fly there. The air is thinner, so the drag and lift are less. Ehrlich writes that they prefer the cooler air to conserve body fluids. The chart of the Earth's atmosphere, in chapter two, shows that the freezing mark is around 8,000 feet. Ehrlich says they are also losing weight, so they gain altitude[14]. Is weight loss that significant?

Perhaps, they are safer from predators or they are not aware of a gradual climb. Why do they get extremely high? They may be lost like the Whooper swan flock at 29,000 feet or the Rüppell's Griffon vulture at 37,900 feet[15].

The bar-headed Goose of Asia may be the highest-flying bird because it migrates at 30,000 feet over the Himalayas from Central Asia to Peninsular (Southern) India[16]. Mount Everest, where intrepid hikers are heard to say, "Will I ever rest?" is 29,035 feet. Birds optimize their flight using the deflection of air off mountain ridges[17]. Other migrating birds fly around 1,000 feet or wherever they find good tail winds[18].

A bird's wing is an effective aerofoil. Birds have an effective aerofoil with a lift coefficient (C_L) and a drag coefficient (C_D). These change with the configuration of the feathers which determine the shape of the aerofoil. They are not affected by the mass of the bird. The lift (L) and the drag (D) are given in terms of these coefficients.

$$L = C_L \frac{1}{2} \rho V^2 A \qquad D = C_D \frac{1}{2} \rho V^2 A$$

Rho (ρ) is the density of the air, V is the speed of the bird and A is an effective area. According to Withers, birds have an effective maximum C_L between 0.80 and 1.20[19].

Jet aircraft fly on the order of 36,000 feet because the air is thinner and there is less drag, but still enough density to provide sufficient lift. The optimum height is often determined by fuel burn, flight schedule and weather[20]. A lighter aircraft can climb because it needs less air to support its weight. Airplanes may fly above the Troposphere to avoid weather, turbulence, and birds[21]. The part of the atmosphere known as the troposphere is shown in the chart of the Earth's atmosphere, in chapter two.

Birds like the vulture or the hawk can soar or fly without flapping their wings. They circle and climb thermals which are rising columns of air. Gliders do the same. Gliders have high aspect ratios which is the ratio of wingspan to wing chord. However, a low aspect ratio airplane like the Red Baron's Fokker triplane is more maneuverable. Vultures are good at soaring because they increase their aspect ratio by extending wingtip feathers[22].

1.1.7 Exceptional Birds

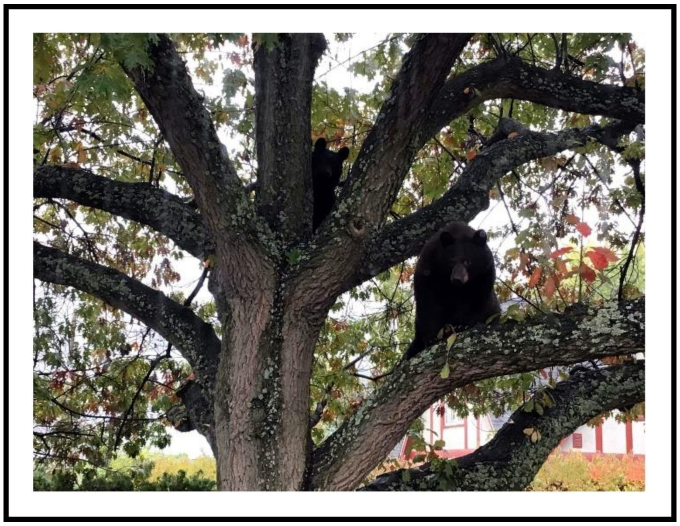
The most intriguing birds master the sky and the water. Birds that chase fish have wettable feathers to reduce buoyancy. They then adopt spread-wing postures to dry the wings[23].

Penguins are also worth a mention. They cannot fly but can escape predators on the land by fleeing to the water. They waddle like a person wearing a tuxedo that is too tight. They have layers of fat to protect them from the icy cold waters they seem to relish. Their wings are small and seem to be adapted to the higher density of water where they get their next meal.

Some may successfully argue the hummingbird is also intriguing. The wings of a hummingbird trace a horizontal figure eight, and the wing angle is adjusted so lift is created by both forward and backward motions[24]. They beat many times a second, so the figure eight is not observable to the bare eye, and it allows the hummingbird to feed on the wing. The hummingbird mastered inflight fueling before the military.

The Peregrine Falcon is also a candidate of interest. It reaches speeds well over 100 mph in a dive. Most birds can cruise around 20 mph, and some fleeing for their lives can reach 60 mph[25]. As mentioned earlier, the Whooper swan, the Bar-Headed goose and high migrating birds are also exceptional.

1.1.8 Other Flying Animals



These bears were foraging for food in an oak tree in Warfield, BC in the Fall before winter hibernation. Alison Watson, an elementary school teacher who took the photos, did not see them fly into or out of the tree.

A bat, not a bear, is the only mammal that relies on true flight. The wing is a membrane stretched over finger bones. It develops lift because the wing has a curved aerofoil shape[26]. Thrust and lift are generated by flapping.

Chickens do fly as the contestants, of season nineteen of Survivor Samoa on CBS in 2009, discovered[27]. During the show, a chicken that the Galu tribe won as a reward escaped from the coop and evaded capture by flying into a tree. While chasing the bird, one contestant got clotheslined by a clothesline. However, chickens have the wrong weight to wing ratio for flight much more than ten feet high or around a dozen seconds long[28].

However, wild turkeys can fly as fast as 35 mph and over distances as far as a mile. The domestic turkey, which has been bred for its breast meat, cannot. The wild turkey can also outrun a horse[29].

Flying squirrels are misnamed because they glide and do not fly like birds or bats[30]. They are nocturnal animals belonging to the mammal class and the rodent order[31]. They have a membrane stretched between the fore and the hind legs. They can steer, and the tail acts like a brake. Some have been known to glide as far as 150 feet.

Insects either fly because of muscles attached to the wings or from the contraction and relaxation of an elastic thorax. The wings flap at high frequencies[32]. Most insects have two sets of wings, but a fly only has one set as well as shrunken vestigial wings called halteres. These are little gyroscopes that help the fly with stability. The wings change their angle of attack or orientation as they flap to make flight possible. As determined from a dead fly, the wings are mechanically coupled[33].

Michael Dillon of the University of Wyoming Zoology department discovered that a bumblebee compensates for lower air density by moving the wing through a greater arc. Insects have been found as high as 19,000 feet while the Rüppell's Griffon vulture of Central Africa has been found at almost twice that height. Neither animal likes the cold, the low air density, and the low oxygen content at high altitudes, but insects are much less suited to the cold than birds[34]. Feathers are good for flight and warmth. Furthermore, insects do not have the sophisticated respiration system of birds.

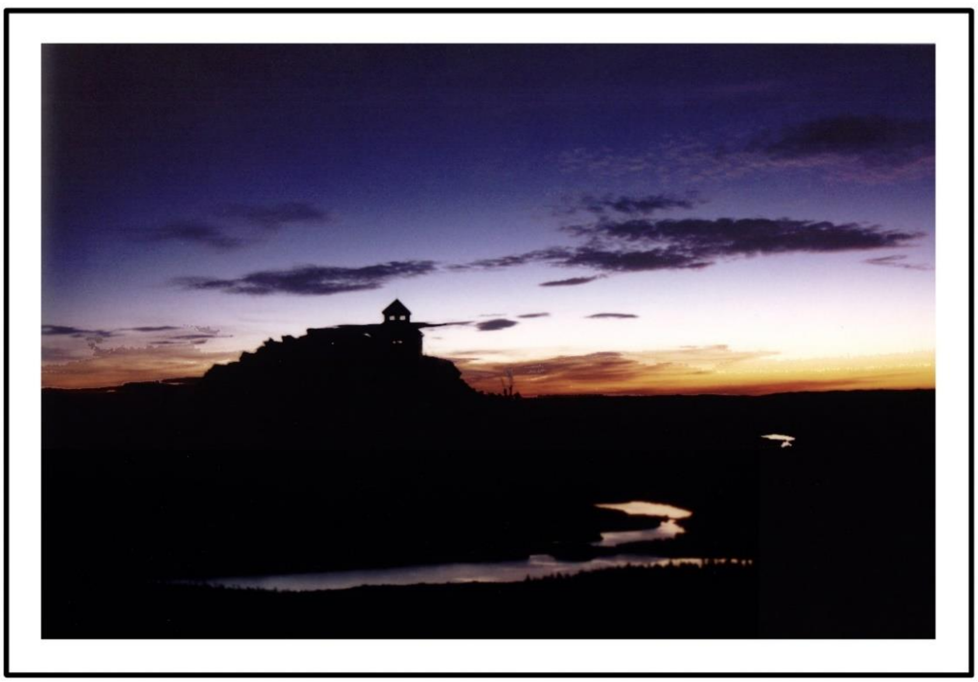
1.2 Sky Phenomena

1.2.1 Sunrise and Sunset

Any photographer will know that the best time for outdoor photography is the four hours just after sunrise and the four hours just before sunset. The lighting when the sun is directly overhead is usually not so appealing.

Sunrise and sunset lead to spectacular photography. They are the same, but a person may think they are different because he is accustomed to the dark at sunrise, while he is used to the light at sunset.

The molecules in the atmosphere scatter blue light more than red light, so the sky looks blue. This is known as Tyndall or Rayleigh scattering. The sunlight at sunrise or sunset has gone through much more atmosphere leaving mostly red and yellow. The Moon has a black sky, like the Earth at night, because it has no atmosphere[35].



The above picture of the sunrise was taken at Mount Carleton Provincial Park in New Brunswick.

1.2.2 Rainbows

A rainbow is artwork created by Mother Nature as an infant. It is beautiful but has childlike simplicity.

A rainbow is the spectrum of white light. The outer arc is red, and the innermost arc is violet. The colours follow the order of Roy G. Biv which stands for red, orange, yellow, green, blue, indigo, and violet. Red has the longest wavelength and violet, the shortest.

Refraction is inversely proportional to the wavelength, so red bends the least and violet the most. A rainbow is seen with the sun at a person's back and the rain out in front. Rainbows are the smallest when the sun is high in the sky.

Any rock 'n' roll fan of Pink Floyd will have seen the front cover of the album *The Dark Side of the Moon*. First, there is no dark side of the Moon because the sun reaches all parts of the Moon's surface over the course of a lunar day. However, the Moon spins so that the same part of the moon is always closest to the Earth because of mutual tidal locking. One side is "dark" or hidden from the Earth.

Second, the album has a prism on the front cover. White light is seen broken down into its spectrum, and red refracts (bends) the least and violet the most.

A double rainbow is two separate arcs[36]. The upper one is fainter, and the colours are reversed because it is a reflection.

A circular rainbow is what is seen from an airplane or a mountain top. A skier could see one from sunlight refracted from snow blowing off trees. The picture above is from Granite Mountain of Red Mountain Resort near Rossland, BC[37]. The locals refer to the sea of clouds with mountain peak islands as the Kootenay Sea.

End Notes

Preface

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[2] A Canadian dollar coin.

About the Author

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Recommendations

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[5] Bennett, Charlie, Personal phone conversation of November 8, 2020. Email conversations of March 27, 2021, April 9, 2021, and April 11, 2021. He read the manuscript and made several suggestions including the addition of flying squirrels and wild turkeys. Thanks.

1. Looking to the Sky

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