The atmosphere of our Earth, of planets of our solar system and of exoplanets

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Publication Date:
2016

Permanent Link:
https://doi.org/10.3929/ethz-a-010580544

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4. Flying and Gliding
Flying and Gliding

Pterosaurian Physics of Flying

4.0 Flying and Gliding: Overview

Flying Men

Physics of Flying

Birds and Insects

Flying Fish and Snakes

Bats and Foxes

Pterosaurian

Flying of Birds and Airplanes

White Stork in Flight

The length of White Storks (from legs to beak) is 80 to 100 cm and their wingspan is 200 to 220 cm. Except for the black wing feathers, the feathering is purely white. White Storks have a mass of about 2.5 to 4.5 kg.

Boeing 747
(Data for 747-100)

- Length: 70.6 m
- Wing span: 59.6 m
- Wing area: 511 m²
- Takeoff velocity: ~ 300 km/h
- Range of Flight: 9'800 km
- Max. Takeoff mass: 333'400 kg
- Average number of passengers: 366
- Average cruise speed: 895 km/h
- Max. operating altitude: 13'000 m
4.1 Physical Basis of Flying

Flying usually means the movement of flying beings (animals and men) through the air. In Physics, flight movements are described on the basis of Aerodynamics.

This first Section contains an overview of the basic principles of flying. A systematic derivation from aerodynamic principles is obtained on the basis of coupled partial differential equations of Navier-Stokes and Euler, (s. Appendix 4-A-1-1). Such a rigorous approach is well beyond the scope of this representation. We rather content ourselves with the simplest possible discussion based on the well-known Bernoulli-equation, from which we derive heuristically the Kutta-Joukowski equation and discuss the most important implications.

On the basis of these strongly simplified equations it is already possible to explain qualitatively the most important aspects of flying. Then, we shall discuss the simple empirical equations for lift and drag, equations which are used by aircraft manufacturers. With some adaptations, these equations will then be used to describe the flight of birds. It is found that the exact shape of the wings and their orientation relative to the airstream is of decisive importance. In addition, it is found that optimum performance is obtained with slightly curved and asymmetric shapes of the wings.
Physically, the air flow around the wing of an animal or an airplane is a highly complex process. During Takeoff, the air flow is usually a turbulent flow and for this reason, the streamlines (lines of constant pressure) around the wings are very complicated.

For a well-defined shape of the wing and air flow, the flow pattern can, in principle, be determined experimentally. On the other hand, the flow pattern can be calculated on the basis of theoretical methods of aerodynamics. For this purpose it is, however, necessary to use complex theoretical equations of aerodynamics such as the Navier-Stokes equations, Euler’s flow theory, the Kutta-Joukowsky Theorem and the Bernoulli equation (s. Appendix 4-A-1-1). In the following, we confine ourselves to Bernoulli’s equation and to the Kutta-Joukowsky Theorem. On this basis we obtain qualitative results for the Lift and the drag (air resistance) of the system (s. Figure below).

The forces acting on the flapping wings of a bird:

\[ \text{Thrust} - \text{Drag} - \text{Weight} - \text{Lift} \]

The resulting force acting on a bird is the superposition of the forces acting on the two wings. The arrows for the forces have been added by P. Brüesch.

The Figure shows the 4 forces which act on the wing of a bird or an airplane.

**Thrust:** A fixed-wing aircraft generates forward thrust when it is pushed in the direction opposite to flight. Birds normally achieve thrust during flight by flapping their wings.

The **Bernoulli Equation** derived in Appendices 4-A-1-2 and 4-A-1-3 reads

\[ p + \frac{1}{2} \rho u^2 + \rho g z = \text{const.} \quad (4.1.1) \]

or

\[ p_1 + \frac{1}{2} \rho u_1^2 + \rho g z_1 = p_2 + \frac{1}{2} \rho u_2^2 + \rho g z_2 \quad (4.1.2) \]

Here, \( p \) is the pressure, \( \frac{1}{2} \rho u^2 \) the dynamic flow pressure and \( \rho g z \) the hydrostatic pressure due to gravity; \( u \) is the velocity, \( \rho \) the density, \( g \) the gravitational acceleration and \( z \) the height. The equation asserts that for a stationary and incompressible flow with negligible friction, the sum of these pressures is constant. This equation can also be expressed as a law of conservation of energy: Using the designations of Appendix 4-A-1-2 and 4-A-1-3, \( \rho = \text{dm/dV} \) is the (constant) density. From \( p \text{ dV} + \frac{1}{2} \rho u^2 \text{ dV} + \rho \text{ dV} g z = \text{const.} \), we obtain the equation: \( (\text{dm/\rho}) p + \frac{1}{2} dm u^2 + dm g z = \text{const.} \). Here, \( (\text{dm/\rho})p \) is the pressure energy, \( \frac{1}{2} dm u^2 \) the kinetic energy and \( dm g z \) is the potential energy. The total energy of a fluid particle of mass \( dm \) following a streamline is constant.

If in equation (4.1.2) the altitude difference \( z_2 - z_1 \) in a flow is negligibly small, equation (4.1.1) simplifies to

\[ p + \frac{1}{2} \rho u^2 = \text{const.} \quad (4.1.3) \]

From this equation it follows, that in a streaming fluid the pressure is the smaller the larger is the velocity: in a horizontal tube, the pressure is smaller in the narrow passages than at paseges with larger diameters. The same is also true for the air flow around an airfoil (s. Ref. R.4.1.13 and pp 113 - 118).
Air flow around Airfoil - 1

In the following we discuss the vortices occurring at the wings of an airplane and the resulting flow pattern. If the air flow passes the airfoil from left to right (see first Figure), one part of the air flows over the airfoil and the other part flows below it.

At the trailing edge, there is a velocity difference of the upper and lower partial air flows. Due to the asymmetric shape of the wing, the upper partial air flow has to pass a longer distance and is decelerated more strongly by friction than the lower partial air flow. [2 c = wingspan, b = mean wing depth of the airfoil].

At the trailing edge of the wing, this produces a free vortex. This is shown in the middle Figure in a two-dimensional representation. It is the so-called starting vortex which is detached slowly from the trailing edge of the airfoil and moves away.

The principle of angular momentum requires a second vortex having a reversed sense of rotation with respect to the starting vortex. This latter vortex circulates around the airfoil as shown in the last Figure. It is called the circulation flow \( \Gamma \), which is superimposed to the parallel flow around the wing (see p. 114).

Air flow around Airfoil - 2

From the technically important theory of airfoils we shall discuss here only the most important aspects. If the airfoil of an airplane is moving through the air, an air flow develops which can be regarded as the superposition of a potential flow (without rotation) (Figure 5a) and a circulation flow \( \Gamma \) (Figure 5b). The development of the circulation has been discussed on p. 113. The resulting air flow is shown in Figure 5c:

The streamlines above the airfoil are squeezed together, while they are much less dense below it. Therefore, according to Bernoulli’s equation (4.1.3) on p. 112 the air pressure above the airfoil is smaller than below it. Hence, the airfoil experiences an upward force which is also called the dynamical lift \( F_A \). \( F_A \) carries the airplane. A qualitative explanation of the lift force \( F_A \) is given on p. 115.

The lift force \( F_A \) depends on the air density \( \rho \), the flow velocity \( u_\infty \), the wing depth \( b \) (s. p. 113) as well as on the circulation \( \Gamma \) (c) where \( c \) is the wing span (s. pp 113, 118). Since the circulation is anti-clockwise, \( \Gamma \) is negative: \( \Gamma < 0 \). A heuristic derivation of \( \Gamma \) and of \( F_A \) is given on pp. 117 and 118. The different vortices of an airplane are shown in Appendix 4-A-1-4.
The **dynamical lift** $F_A$ is defined as the force which acts on a body immersed in a uniform flow perpendicular to the flow direction. This is the case if the circulation around the body is different from zero (s. p. 114).

The circulatory flow $\Gamma$ which is superimposed to the potential flow increases the flow velocity $u_1$ around the upper surface area ($u_1 > u_\infty$), while the flow velocity $u_2$ around the lower surface area is decreased ($u_2 < u_\infty$). Therefore, $u_1 > u_2$. (s. Figure, p. 114).

According to Bernoulli's equation the difference of the flow velocities is approximately equal to the pressure difference (s. p. 117), i.e. $p_2 > p_1$. Since $p_1 = p_1(x)$ and $p_2 = p_2(x)$ (x-coordinate s. pp 113, 117) the lift force is given by

$$F_A = b \int_0^c [p_2(x) - p_1(x)] \, dx \quad (4.1.4)$$

where $b$ is the effective or average wing depth and $c$ is the wing span (s. Figures pp 113, 117).

The Kutta-Joukowski equation (pp 116 - 118) is a quantitative relation between the circulation $\Gamma$, the approaching velocity $u_\infty$, the density $\rho$ of air and the lift force $F_A$ for the case of frictionless flow around the airfoil (s. Figures on pp 113, 117):

$$F_A = - \rho b \Gamma u_\infty \quad (4.1.5)$$

The circulation $\Gamma(c)$ will be defined on pp 116 – 118 and a discussion is given on the basis of a simple example. Due to the direction of rotation $\Gamma < 0$ and hence $F_A > 0$.

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### Theorem of Kutta - Joukowski and Lift of an Aifoil

According to equation (4.1.5) the lift force $F_A$ is given by

$$F_A = - \rho b \Gamma u_\infty \quad (4.1.6)$$

$\rho$ = density of air; $b$ = average wing depth (see pp 113, 115)

$u_\infty$ = undisturbed wind velocity (see pp 113 - 115);

$\Gamma$: circulation around airfoil ($\Gamma < 0$, s. pp 113 - 115) $\Rightarrow F_A > 0$.

The circulation $\Gamma$ introduced by Kutta-Joukowski is defined as the line integral

$$\Gamma = \oint_C \vec{u} \, ds = \oint_C u \cos(\theta) \, ds \quad (4.1.7)$$

over a curve $C$ surrounding the airfoil (see Figure below).

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![Diagram of Kutta-Joukowski theorem](image-url)
**Heuristic Model for the Circulation \( \Gamma \) and the Lift \( F_A \) - 1**

The circulation \( \Gamma \) as defined by Kutta-Joukowski (Eq. (4.1.7)) is required for the calculation of the lift force \( F_A \) (Eq. (4.1.6)). An exact evaluation of \( \Gamma \) is beyond the scope of this presentation (see Ref. R.4.1.4 for a derivation). The following heuristic consideration is not exact but illustrative (Ref. R.1.4.5 e). We first consider the airfoil shown below.

\[ F_A \approx b \int_0^\infty \Delta p(x) dx = b \rho u_\infty c \int [u_1(x) - u_2(x)] dx \tag{4.1.9} \]

A closer inspection of the integral shows that it corresponds to the negative circulation around the airfoil. The circulation is given by

\[ \Gamma = \int_0^c u_2 dx + \int_0^c u_1 dx = -c \int_0^c (u_1 - u_2) dx = -c \int_0^c \Delta u(x) dx \tag{4.1.10} \]

From (4.1.5) we obtain a relation between the lift force \( F_A \) and the circulation \( \Gamma \):

\[ F_A = -b \rho u_\infty \Gamma = +b \rho u_\infty \int_0^c \Delta u(x) dx \tag{4.1.11} \]

In a first approximation we replace \( u_1(x) \) and \( u_2(x) \) by constant mean velocities \( u_{1m} \) and \( u_{2m} \). Then we obtain for the mean circulation \( \Gamma_m \):

\[ \Gamma_m = -c (u_{1m} - u_{2m}) \tag{4.1.12} \]

and the mean lift force \( F_{Am} \) is then given by

\[ F_{Am} = -b \rho u_\infty \Gamma_m = +b c \rho u_\infty (u_{1m} - u_{2m}) \tag{4.1.13} \]

Let \( u_{1m} \approx \bar{u}_x + u_{circ} \) and \( u_{2m} \approx \bar{u}_x - u_{circ} \), where \( u_{circ} \) is the circulation velocity; then we obtain with \( u_{1m} - u_{2m} \approx 2u_{circ} \)

\[ \Gamma_m \approx -2c u_{circ} \]; therefore

\[ F_{Am} \approx 2b c \rho u_\infty u_{circ} \tag{4.1.14} \]

**Heuristic Model for the Circulation \( \Gamma \) and the Lift \( F_A \) - 2**

\[ F_A \approx b \int_0^\infty \Delta p(x) dx = b \rho u_\infty c \int [u_1(x) - u_2(x)] dx \tag{4.1.9} \]

A closer inspection of the integral shows that it corresponds to the negative circulation around the airfoil. The circulation is given by

\[ \Gamma = \int_0^c u_2 dx + \int_0^c u_1 dx = -c \int_0^c (u_1 - u_2) dx = -c \int_0^c \Delta u(x) dx \tag{4.1.10} \]

From (4.1.5) we obtain a relation between the lift force \( F_A \) and the circulation \( \Gamma \):

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\[ \Gamma_m \approx -2c u_{circ} \]; therefore

\[ F_{Am} \approx 2b c \rho u_\infty u_{circ} \tag{4.1.14} \]

4 – 6
Lift coefficient: Technical relation and Kutta – Joukowski

In the technical literature, the following formula for the lift force is often used:

\[ F_A = \frac{1}{2} C_A b c \rho u_\infty^2 \]  (4.1.15)

Here, \( C_A \) is the so-called Lift coefficient. Among others, \( C_A \) depends on the details of the airfoil (inclination \( \alpha \), s. p. 117) and shape. In order to gain an approximate expression of \( C_A \) we identify \( F_A \) with the theoretical formula (4.1.6) or (4.1.11): \( F_A = F_A^* \). We then obtain

\[ \frac{1}{2} C_A b c \rho u_\infty^2 = - b \rho u_\infty \Gamma \]  (4.1.16)

or

\[ C_A = - 2 \frac{\Gamma}{(c u_\infty)} \quad \text{bzw.} \quad \Gamma = - \frac{1}{2} C_A c u_\infty \]  (4.1.17)

[Note that \( \Gamma < 0 \) and therefore \( C_A > 0 \).]

In order to illustrate eq. (4.1.17) we replace the exact expression of \( \Gamma \) by its expression from the heuristic model, namely \( \Gamma_m = - 2 c u_{circ} \) (Eq. (4.1.14)), and obtain for the corresponding lift coefficient \( C_{Am} \):

\[ C_{Am} = 2 \left( u_{1m} - u_{2m} \right) / u_\infty = + 4 u_{circ} / u_\infty \]  (4.1.18)

Example: let \( u_{1m} = 1.28 u_\infty \) and \( u_{2m} = 0.72 u_\infty \); then \( u_{circ} = (1/2) \left( u_{1m} - u_{2m} \right) = 0.28 u_\infty \) and \( C_{Am} = 1.12 \).
4.2 Flying and gliding animals

4.2.1 Invertebrates and Vertebrates

Invertebrates

- Invertebrates are defined as animal organisms without backbones. Invertebrates do not have an internal skeleton, but often they do have an exoskeleton.
- The majority of the living creatures belongs to this animal species.
- Examples of Invertebrates:
  - Insects
  - Molluses (e.g. Snails)
  - Ringel worms (e.g. Leeches)
  - Cnidarians (e.g. Jellyfishes)
  - Protozoas (e.g. Amebas
  - Squids

Vertebrates

- The species of Vertebrates has an endoskeleton with a backbone at the centre.
- Vertebrates belong to the higher developed animals.
- Examples of Vertebrates:
  - Mammals (e.g. Humans)
  - Birds
  - Fishes
  - Reptiles (e.g. Snakes)
  - Amphibians (e.g. Frogs)
The biological – geological time scale

Contraction of geologic age on one day

<table>
<thead>
<tr>
<th>Age in Mio. years</th>
<th>Development</th>
<th>Age in days</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01</td>
<td>Agriculture and stock farming</td>
<td>0.2 s</td>
</tr>
<tr>
<td>0.13</td>
<td>Homo sapiens</td>
<td>2 s</td>
</tr>
<tr>
<td>1.5</td>
<td>Homo habilis</td>
<td>25 s</td>
</tr>
<tr>
<td>7</td>
<td>Upright walking</td>
<td>2 min</td>
</tr>
<tr>
<td>10</td>
<td>Pre-hominids</td>
<td>3 min</td>
</tr>
<tr>
<td>33</td>
<td>Grate apes</td>
<td>10 min</td>
</tr>
<tr>
<td>80</td>
<td>Monkeys</td>
<td>20 min</td>
</tr>
<tr>
<td>200</td>
<td>Mammals</td>
<td>1 h</td>
</tr>
<tr>
<td>280</td>
<td>Reptiles</td>
<td>1 h 20 min</td>
</tr>
<tr>
<td>360</td>
<td>Amphibians</td>
<td>1 h 45 min</td>
</tr>
<tr>
<td>420</td>
<td>Fishes</td>
<td>2 h</td>
</tr>
<tr>
<td>470</td>
<td>Vertebrates</td>
<td>2 h 15 min</td>
</tr>
<tr>
<td>600</td>
<td>Multicellular organism</td>
<td>3 h</td>
</tr>
<tr>
<td>1000</td>
<td>Sexuality</td>
<td>5 h</td>
</tr>
<tr>
<td>1500</td>
<td>Eukaryotes</td>
<td>7 h</td>
</tr>
<tr>
<td>2200</td>
<td>Photosynthesis</td>
<td>11 h</td>
</tr>
<tr>
<td>3200</td>
<td>Protozoons</td>
<td>15 h</td>
</tr>
<tr>
<td>4600</td>
<td>Earth</td>
<td>23 h</td>
</tr>
</tbody>
</table>

The geological time scale is a Table which structures the history of the Earth chronologically and hierarchically. (in the Table from the bottom up)

Since the beginning of the ages of verifiable life 542 Mio. years ago, the continuous fossil record sets in. Based on the methods of biostratigraphy, a differentiated classification was possible.

In the opposite geological Table, the older periods are below, the younger above, similar to the series of the sedimentary rocks within an idealized and undisturbed tectonic layered segment.

Examples of flying or gliding invertebrates and vertebrates are shown at p. 123 and discussed in Sections 4.2 and 4.3, respectively.

Known living beings on Earth

Insects are divided into many groups. Examples of these groups are bugs, butterflies, gnats and others. As can be seen from the picture, the largest group contains the bugs. There exist over 250’000 species of bugs.

H: Hymenoptera
Ol: Other Insects
OG: Other Groups
M: Molluscs
V: Vertebrates
OAA: Other Articulate Animals

Although these 250’000 species of bugs are all different, they do have something in common: All bugs are protected by a hard chitinous exoskeleton. Below this skeleton, there are two delicate foldable wings.

As all Insects, bugs are moving with three pairs of jointed legs. The pair of antenna is used for palpation. After birth, the bugs are grubworms. Later, the grub pupates and develop into a bug. The red flashes of the Figure indicate the different species of Insects.

It should be noted, that the vertebrates constitute only a small part of all living beings.

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What are Insects?

The notion «Insects» derives from the Latin word «Insecare», what means «incise» and refers to the three body segments (head, breast and abdomen).

The science of Insects is called Entomology.

Insects are Invertebrates, i.e. in contrast to mammals, fishes, reptiles, amphibians and birds, they do neither posses a backbone nor an inner skeleton. They belong to the stem of Anthropods, which are characterized by their segmented legs and their rigid, protecting exoskeleton.

Insects differ from the other arthropods by having only three pairs of legs and that they posses only one to two pairs of wings. For this reason, spiders and scorpions do not belong to the class of Insects.

A very large number of Insects are flying animals. However, besides the flying Insects there exist also non-flying Insects. Examples of the latter are cicadas, moths and stoneflies.

For the present topic of «flying animals» we are only concerned with flying insects.
The Planet of Insects

The animal world can be subdivided into Protozoon and multicellular organisms. The latter contain about 30 animal phyla, to which belong the arthropodes (arthron = limb and podes = feet). Arthropodes comprise more than 80% of the animal world, and 75% of them are Insects. Every day, new species are discovered. Some scientists believe that more than 50 millions of new species are waiting for discovery.

Bugs are the largest family, containing more than one Million of species; they are followed by the Butterflies with about 180'000 known species (s. p. 123). Butterflies are followed by Flies and Gnats. These are finally followed by Hymenopterans (Hautflügler). In addition, there exist many other Insects: at p. 123 they are contained under «Other Insects (Ol)».

The first Insects populated our Earth about 400 Million years ago; they belong to the most original animals of our Planet. In addition, they are the most adaptable animals of the Earth. In contrast, while species such as the Dinosaurs died out, Insects always developed further and continuously reproduced themselves. Because of their enormous adaptability, Insects were able to populate each place of the Earth: they are living in the Air, in water in woods, etc.

Corresponding to the special physiology of the Insects, bugs have two pairs of wings, but only the hindwings are adapted for flying, the forewings are sclerosed. Most bugs are able to fly, many of them very well, others less well. There exist bugs who are able to fly excellently and reach maximum velocities up to 8 m/s.

Largest and smallest flying Insects of the world

If one is searching in the Literature for the largest or smallest flying Insects of the world, it is not possible to find a clear answer. Below, two examples are shown which belong to the best candidates.

One of the Earth’s largest Insect is a butterfly. The largest known butterfly is the Queen Alexandra’s birdwing. The female wingspan slightly exceeds 25 cm and its body length is 8 cm. The wingspan of males is smaller, about 20 cm but more usually about 16 cm.

The smallest insect ever found is a fairy wasp, the so-called «Dicopomorpha Echmepterygis». (I am indebted to Mister Peter Etter for giving me this information).

The male has a length of only 0.14 mm but it is unable to fly and is blind. The females have a length L of about 0.2 mm and are capable of flight. The Reynolds number Re = (ρ L u²) / ν (s. 4-A-2-1), has an order of magnitude of Re = 1 (s. p. 4-A-2-2).
Insects are invertebrates: they do not have a backbone. They do have, however, a solid exoskeleton-chitin crust and six segmented legs. The body of the Insect is segmented into three sections (s. also p. 129): head, breast and abdomen. Eyes, mouthparts and feelers are part of the head, while legs and wings are connected to the middle thoracic segment. The abdominal segment contains the heart, the intestine and the reproduction organ of the Insect.

Not every creepy-crawlies is, however, an Insect! Spiders and crustaceans are similar to insects, but they are forming their own group of animals. The most characteristic feature of insects is really the separation of their body into three segments.

Bees are social insects (s. p. 130). For the regeneration, often very view sexual animals are active. In the case of bees, only the Queen is lying fertilized and unfertilized eggs.
The highlight of the bee’s year is the swarming season, during which part of the natural reproduction takes place (from April to June). This happens if the beehive is overflowing from honey and bees. The bees rush out of the emergence hole as a waterfall and produce a raging sound. This 10 to 20 m large cloud of bees is moving peacefully and at walking pace. The queen recides in the centre of this cloud. If they have found an appropriate location, they settle down again.

Only sexually mature males and females possess wings. For the purpose of mating, the flying ants leave in swarms their anthill and set off for honey-moon: The mating takes place at a height of 10 to 15 m. Ants take care for an intact ecological equilibrium: To these belong the destratification of the upper soil levels, the elimination of waste products and of small harmful insects from their hills.

Termites are a colonising order of insects and belong to the class of flying insects. A colony of termites can comprise several millions of individuals. The sexually fully developed animals have compound eyes. After swarming (nuptial flight), they quickly get rid of the wings with a simple body flick. The remnant of a wing is a distinct triangular scale.

Butterflies are Insects (Lepidoptera). From the biological systematics they form an own order within the Insects. Worldwide there exist about 200,000 different species of butterflies. In Middle-Europe, more than 3,000 species are known. In contrast to other Insects, they are distinct in that they possess wings with scales (see p. 133).

The comma is an adult animal. Its primary task is to produce descendants (p. 132), and to insure that the fertilised eggs are oviposited at places where they can develop without disturbance.

For this purpose, the females oviposit the eggs at secure locations, for example at the underside of a plant’s leaf, where they are protected from rain and sunshine.

Depending on the species, the eggs of butterflies vary in size and in shape but as a rule, the eggs have diameters between 0.4 and 2.6 mm. The larvae emerge from the eggs after a few days; for butterflies, these larvae are called popating butterfly caterpillars (p. 132).
Development of a Butterfly

Depending on the climate, the life cycle of a species varies between a few days and four years.

Wings and Flight characteristics of Butterflies

With a few exceptions, the wings are the musculoskeletal system of butterflies. The forewings and the hindwings are individually suspended but during flight, they are coupled by special mechanisms. Day-flying butterflies do not, however, possess such a coupling.

The wings of butterflies are much more sensitive than those of flies. Both, the upper and lower wing surfaces are covered with scales; these scales provide the necessary stability of the very thin wing-skins which is important for their flight capability. The interference of light at the scales produces impressive colors of the wings.

Left: Scales of a wing enlarged by a factor 25.

Flight characteristics

Depending on the butterfly species and the wing shape it is possible to distinguish between different flight patterns. The latter depend on the characteristics and velocity of the wing flap and the locomotion: flapping flight, quiet hovering flight, gliding flight, soaring flight, etc. The wings are set in motion by various muscles of the thorax. They are not only flapping up and down but rather rotate simultaneously around the wing base thereby executing a complicated «figure-8 motion». The so-called howkmoths belong to the rapidly flying butterflies. They can move at a speed up to 50 km/h. If they are sucking nectar they can stop their flight or even fly backward. The very small butterflies do not fly by flapping the wings but are rather floating through the air by the force of the wind. In general, the wind is an important means of transport.
In order to be able to fly efficiently in active flight inspite of their small wings (picture below), a rapid wing beat is required. The fruit fly (Drosophila melanogaster), is flapping their wings with a frequency of 200 – 250 vibrations per second (200 – 250 Hertz). Their flight muscles are thus contracting and relaxing 200 to 250 times per second.

How can the fruit fly achieve such a high flapping frequency? Their trick of flying is astonishingly simple: The contractions of the flight muscles are not only controlled by nerve impulses but also by tension. For this purpose, the fly has two kinds of flight muscles: one of them are moving the wings downwards, thereby expanding the other muscles which are then contracted again. In this way, the wings are moving again upwards – a highly effective interplay.

The ordinary fruit fly can change the direction of its flight by 90 degrees in about 50 milli-seconds!

Fruit fly in gliding flight: the wings do barely move. The length of the fly is only a few mm.

Fruit fly in active flight; the flapping frequency of the wings is very high!

Tsetse flies are living in Africa; they live on human blood and on animal blood, thereby transmitting the dangerous sleeping thickness.
Mosquitos

Gnats or mosquitoes are a family of insects belonging to the order of diptera. Worldwide, there exist more than 3'500 species of gnats.

With the help of their specialized mandibles, the female mosquitoes are able to pierce the skin of their hosts and to suck their blood. The proteins obtained in this way are needed for the production of eggs. In addition, the mosquitoes subsist on nectar and on other sucrose-containing plants.

Some distinct mosquitoes are known as pathogens such as Malaria or Dengue fever. Even today, over one million people worldwide die from mosquito-born diseases every year!

Flight characteristics

Mosquitos are able to fly with a velocity up to 1.5 to 2.5 km/h. In general, their flying height depends on the actual species, on the altitude above sea level, on weather and air pressure, on the temperature and on the conditions of illumination. In the case of warm, calm and slightly cloudy weather and in the absence of direct sun exposur, the activity of mosquitoes is particularly strong. In this case, some species are able to reach large flying heights of more than 100 meters. At cool or rainy weather, however, many mosquitoes are flying only small distances and rather remain near the ground. If there are fresh breezes and temperatures near the freezing point, they stop completely their flight activities.

4.2.5 Hymenoptera (Hautflügler)

Wood wasp
Sawfly in flight

To the family of hymenoptera there belong such well known insects as the bees, wasps and bumblebees. For human beings, bees are probably the most important group of insects.

The number of hymenoptera known up to day is of the order of 100'000. But it is to be expected that this number will increase considerably, if in tropic regions small wasps are investigated on a systematic way. Species of the order of hymenoptera are present in nearly all habitats: from the tropic rainforest to the desert areas.

The majority of the hymenoptera has two membranous and transparent double-wings, from which the hindwings are smaller than the forewings. The functional double-wings have a very positive effect on the air worthiness.
4.2.6 Dragonflies (Drachenfliegen = Libellen)

The flying skills of dragonflies are spectacular, perfected in millions of years of evolution. Large dragonflies, for example, can accelerate very rapidly and reach velocities up to 40 km/h. From full flight they can decelerate abruptly and change their flight direction very quickly and they can even fly backwards. With the help of wind assistance, some species are able to fly distances up to 1000 km in just a few days: they can fly from mediterranean areas across the Alps to middle Europe. On the other hand, small dragonflies (damselflies) are especially impressive by their extreme maneuverability.

These accomplishments are achieved by a very strong flight musculature and by light but nevertheless strong stable wings (the mass of the 4 wings of a large dragonfly is only about 10 mg, while their total mass is about 1 g). Furthermore, the two pairs of wings can be moved independently and since each wing is controlled by its own pair of muscles, it can be adjusted individually according to the specific requirements. At normal flight, the flapping frequency of the wings is relatively small, only about 30 times per second and they are flying nearly soundlessly. The corresponding frequency of flies and gnats (p. 135) is much higher, namely 200 to 250 times per second.

Comparison between Dragonfly and Helicopter

The flight characteristics of a Dragonfly is comparable with that of a Helicopter:

- Both can perform «Vertical Take Off and Landing» (VTOL)
- Acceleration from full flight
- Abrupt deceleration
- Sudden change of direction of flight
- Backwards flight
- Excellent maneuverability

[The lift of Helicopters is due to the flow of air around the rotating propellers. Their profiles resemble that of a static airfoil (s. pp 113 – 119) and Reference R.4.2.19); therefore, the lift is due to the reduced pressure at the upper surface of the rotor blades where the velocity of the air stream is larger than at the lower surface of the blade. Helicopter: see pp 188, 189].
4.3 Flying and Gliding Vertebrates

The Phylum (Stamm) of Vertebrates contains 5 Classes:

- Birds
- Fishes
- Reptiles
- Amphibians
- Mammals

4.3.1 Flying Pterosaurs

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Pterosaurs (Flugsaurier) are extinct animals and similar to the Dinosaurs they can be assigned classically to the Reptiles. In contrast to Dinosaurs they were able to glide or even to fly.

The earliest archeological finds of Pterosaurs showed that they existed from the late Triassic to the end of the Cretaceous period (228 to 66 million years ago). Pterosaurs are the earliest vertebrates known to have evolved powered flight. Their wings are formed by a membrane of skin, muscle, and other tissues stretching from the ankles to a dramatically lengthened fourth finger.

The Pterosaur shown in the picture is the largest known flying creature. Scientist estimate that the Texas Pterosaur had a wingspan of about 15 m, - larger than most of modern supersonic aircrafts!

The most apparent characteristic of Pterosaurs are the front legs which were modified into large wings. With the help of these wings, the Pterosaurs were able to glide or even to fly.

As a rule, the long wing bones were hollow and very thin walled. They contained many air-filled regions. As a consequence, the weight of the bones was small. By trabeculae, the bones were strengthened, in particular the long bones. [The bone is spongy and consists of a lattice of delicate bars of bones called trabeculae and is less dense than compact bone. The orientation of the trabeculae is affected by the mechanical stress to which the bone is exposed]. For this reason, only fragments of the wing bones have been found; intact wing bones have been seldomly discovered.

Compared to the other Reptiles, the backbone of the Pterosaurs are distinctly different and is adapted to the flying lifestyle. Some parts of the backbone are very similar to the backbones of birds: a very pronounced shoulder region and a massive region in the area of the pelvis («Becken» in German).
The wingspan of the largest Pterosaurs was 11 – 13 meters. Because of their hollow bones, the mass of these large animals was comparatively small, only about 100 kg; according to other sources, their mass was up to 200 kg. In contrast to their very large wingspan, the body was small. This species was presumably not an enduring flyer, but was rather able to cover long distances by gliding in thermal air currents. In this way, they were able to remain in the air for hours with a minimum of energy expenditure.

How exactly they were able to fly upward from the ground into the air in spite of the weight and their huge wingspan is still controversial. While the smaller animals were probably good flyers, it is assumed that also the large Pterosaurs were able to leave the ground by their one force; but to achieve this they required favourable wind conditions.

It is unclear of whether the long and pointed bill was equipped with teeths; furthermore, it is not known of whether the animals were walking on two or on four legs.
4.3.2 Die Vögel: Physiologie, Flugtechnik und Beispiele

Birds: History - Masters of the Air - Examples

History of Birds

The history of birds started about 200 million years ago. The picture alongside shows the alleged appearance of a fossil bird, the Archæopteryx (redesigned after the original of Maurice Wilson in W.E. Swinton: Fossil Birds, London (1965)).

From the picture shown in the reconstruction it is clearly seen, that the Archæopteryx with his bird-like skull, his talons, wings, feathers and his wishbone (Gabelbein) is quite similar to a bird. Apart from birds, no other animal has feathers and wishbones. The structure of the feathers is highly complex; they are optimally suited for their destined structures, i.e. for their aerodynamic functions as well as for heat accumulators.

Fossil records which have been classified as birds, show the relationship with her ancestors, the reptiles. The size of the oldest known fossil bird shown above, was similar to the size of a small pigeon. From this fossil bird, only a single feather and 7 completely or partially conserved imprints have been discovered, all of which descend from the upper Jurassic (between 157 and 145 million years ago).

Birds are found on all Continents of the Earth; they are able to adapt themselves to nearly every living space. Today, about 9000 species exist. They are living in apparently uninhabited deserts or in the Antarctic, in wildwoods, swamps, rock coasts, forests, fields and in cities.
Habitus of a Bird

The two wings correspond to the two arms of the Bird

Figur lettering translated from German
To English by P. Brüesch

Physiology of Birds: The Skeleton - Bones

Longitudinal section through the bones of a Bird

In order to achieve the small body-weight necessary for flying, the bones of birds are to a large extent hollow.

Nevertheless, depending on the group of birds, the degree of pneumatization is developed to a different degree.

Cross section through the bone of a Bird

The trabeculae provide the necessary stability.
The weight of the skeleton is only 6 – 8% of the total body weight.
(for mammals: 20 – 30%)

Bone of a Bird (longitudinal section)
The wings of birds are movement organs used for flying. They have been developed by a transmutation of the forelimbs. During flying they generate lift and thrust (s. p. 111).

The plumage (feathering) consists of large flight feathers and shorter pinions. For the upper and lower wings, the latter form the wing-covers. The flight feathers are the largest feavers on the wing and are divided into primaries and secondaries. They are forming interlocking tiles. For flightless birds such as ostriches, the flight feavers are usually largely reduced.

As shown in the Figure below, the interconnection of the feathers is very complex.

Microscopic picture of a bird’s feather:
Interconnecting tiny hooklets, barbs and barbules are stabilizing the feather.

Remarks about the Dynamics of the Flight of Birds

The physical principles underlying the flight technique of airplanes have been discussed in detail in Section 4.1 (pp 109 – 119). The same principles do essentially also apply for the flight of Birds: At a stretched flapping wing (gliding flight) the lift is produced in the same way as for an airfoil which is subjected by an air current acting from the front of the wing.

However, for the case of the flight of a Bird, there is an essential complication due to the dynamics of the wings i.e. due to their flapping motion.

Lift and thrust depend essentially on the wing shape as well as on their upstroke and downstroke motion.

At the upstroke of the wings, the air impinges the wings essentially from above while at the downstroke of the wings, the air impinges the wings essentially from below. The associated forces are small in the vicinity of the wingroots and increase towards the wingtips.

During the downstroke of the wings, the local overall distribution of the lift force is larger than for gliding motion and more shifted towards the wingtip. Due to this batting movement, a thrust force (p. 111) is created along the total length of the wing. The functional principle is similar to a propeller blade having a very large pitch (ascent angle), with the exception that in the case of birds the longitudinal propeller force acts as a lift force.

A similar flight technique exists in principle also for insects. But due to the small size of insects compared to that of birds, there are not only similarities but also some important differences of the flight dynamics (s. Section 4.2).
The fastest flyer: The fastest Bird is the falco peregrinus (Wanderfalke) with a maximum air speed of 389 km/h (!) and an average diving speed of about 250 km/h. His average speed lies between 50 – 100 km/h.

Highest flying bird: Most bird species are flying abot 100 to 2000 m above ground. Migrating birds however, are climbing frequently up to 10’000 m, für example if they are crossing the Himalaja. The observed record is 11’000 m for the african ruspelli griffen (Sperbergeier). It is astonishing that the animals have the necessary physical strength inspite of the reduced oxygen concentration (Chapter 2, p. 301).

Long distance flyers: Record holder in long distance flights is the Arctic tern (Küstenseeschwalbe). From all migrating birds it is the one who is flying the longest distances. The bird is breeding in the Arctis and than migrates to the Antartics where it overwinters. The total travel distance in both directions lies between 30’000 and 50’000 km. This corresponds roughly to the circumference of the Earth (= 40’000 km).

Longest staying birds in the air: No bird is staying longer in the air than the alpine swift (Alpensegler): It has been ascertained recently that this bird is able to cover a non-stop flight of 200 days! Another bird who is also able to stay a very long time in the air is the common swift (Mauersegler) (s. Appendix 4-A-3-4).
The Anden condor is a bird species belonging to the New World vultures. Adult mail animals are large and black raptorial birds. The Anden condors are giant, black birds with distinct white to silvery hawlings. A white ruffle separates the reddish-blue head from the trunk. They are the largest raptorial birds having a weight up to 15 kg and at the same time, they belong to the few birds with a wing span of more than 3 meters!

4.3.3 Gliding of Fishes - 1

Certain saltwater fishes are referred to as «flying» fishes. By means of self-propelling these fishes are able to perform jumps out of the water into the air. With the help of their long wing-like fins they are able to cover large distances over the water by means of gliding flights. This exceptional skill is a natural mechanism of self-defense against predators.

It is often observed how flying fishes are jumping out of the ocean water. Their streamlined torpedo-shaped habitus makes it possible to generate sufficient underwater velocity and together with their large wing-like pectoral fins they become able to fly.

The process of gliding in the air starts with the generation of high speeds close below the water surface, about 60 km/h. Once in the air, they achieve gliding heights up to 1.2 meters and they are able to glide over distances as large as about 200 meters.
Flying fishes are living in all Oceans, most often in warm, subtropical water. They are usually smaller than 30 cm; the largest of them are up to 45 cm.

Flying fishes are bone fishes; with their wing-shaped fins, they are equally well capable to swim in water as to glide in the air. The rounded profile of the «wings» is comparable to the aerodynamic form of bird wings. But in contrast to birds, they are unable to flap their pectoral fins and for this reason they can not fly actively. With a leap, they rather catapult themselves out of the water and are then able to glide short distances above the water surface.

Flying fishes have extraordinary large pectoral fins which are fixed at the upper part of their body. For the subfamily Cypselurinae, also the ventral fins are winglike such that even 4 wings are available for gliding flight.

The largest flight routes are achieved, if these fishes are gliding very close to and parallel to the water surface: If they are gliding in a height of 1.5 meters above the surface, the fishes can stay more than 30 seconds in the air, thereby covering distances of about 50 meters; in extreme cases the gliding distance is even as large as 400 meters !

The excellent flight capabilities of these fishes are due to the fact, that the configuration of their fins are very well suited to achieve aerodynamically favorable characteristics of flight currents.

Occasionally, the fishes are able to reach velocities up to 70 km/h during their gliding flights and achieve flying heights up to 5 meters.

Sharks are cartilaginous (Knorpel-) fishes and therefore lighter than bony fishes. Worldwide, about 500 species are known. Most of the sharks feed on fishes and other marine creatures. Although only about 5 people are dying per year due to shark attacks, sharks are considered to be cold-blooded killers and ogres (Menschenfresser). Within the carnivorous and hunting species, the White Shark (Jaws; remember Steven Spielberg) with a maximum length of 7 meters is the largest shark.

Sharks have oil-containing livers which contribute to their lift. In South Africa, the sharks have developed a special technique for seal (Robben) hunting: When seals cross deep water, the sharks, swimming at great depth, dart with great speed towards their victims near the surface. In doing so, they often shoot far beyond their target, i.e. they cross the water surface and are then gliding up to 200 meters across the air. During their gliding motion they admittedly touch the water several times but without immersing into it. The lift necessary for the gliding flight is favored by their oil-containing liver as well as by their light bones. In addition, the movement of their tail contributes to the lift.
4.3.4 Gliding flight of Reptiles

Reptiles are a group of animals that have scales (Schuppen), breathe air, and usually lay eggs. The term «Reptile» is loosely defined in everyday English to mean scaly, cold-blooded, egg-laying animals. The two most important features of Reptiles are:

- They are cold-blooded
- They are covered with scales

Being cold-blooded means that their bodies react to the temperature of their surroundings. They prefer warm surroundings but when they get too warm, they moove into the shade or into the water.

Common Reptiles include alligators, crocodiles, lizards (Echsen), snakes, tortoises (Landschildkröten) and turtles (Wasserschildkröten). One of the most remarkable feature of Reptiles are the scales that cover their body.

Some gliding Reptiles:

There are no flying Reptiles, but a few of them are able to glide:

- Gliding Kites (lizard)
- Gliding Geckos
- Gliding snakes

Flying Dragons

Flying dragons are a species of the family of lizards (Echsen). They are living on trees in the rain forests of South-East Asia, in particular on the Islands of the Malayan archipels.

Flying dragons have a size of 20 to 26 cm. They possess flying membranes which are stretched by 5 to 8 extended ribs. Using these membranes as sails, they are able to glide from one tree to the next one. Most often they bridge only a few meters, but they are also able to cover gliding distances of up to 60 meters. The skinny sails as well as the throat sack are often multicolored and in resting position they are laterally back folded to the body.
Geckos are a family of scaled reptiles. They populate the Earth since about 50 million years and during their development they spread out globally.

Geckos are small to middle-sized lizards with sizes ranging from 1.6 cm up to almost 40 cm. About 75% are twilight- and nocturnal active animals and correspondingly, their coloration is quite modest.

Flying Gecos have airfoils at the extremities, at the tail and at the the body sides. Geckos are bug hunters. The tinge of the membranes is barklike and hence unobtrusive. In their resting position, these barklike membranes serve as a cover against predators.

Their toes are connected by a tissue. Due to the above mentioned airfoils and the tissue between the toes, they are excellent gliders.

Five related colubrid species in Asia are not only crawling across the ground but they are also «flying» through the air!

These «flying snakes» are considered to be biomechanical miracles: They do not possess wings, but nevertheless they are able to «fly». Strictly speaking, they are gliding through the air. For this purpose, they are leaving a tree or a higher object, thereby making their body flat like a sail. Then, they are gliding from one tree to another tree or to the ground. During their gliding motion, the colubrids are able to stay in the air by a wavelike spiral movement of their bodies. They are, however, not able to fly actively up to higher altitudes.

«Flying snakes» constitute a small group of tree snakes. Only five known related species belong to this group, all of which are so-called «Golden Tree Snakes». They are living in Southeast Asia and in South Asia. The lengths of the adult reptiles varies between 60 cm and 120 cm. If the diurnal snakes are biting, they excrete a weak poison which is only dangerous for their preys such as Gecko’s. frogs, birds and bats.

The reason of why these snakes are gliding is not known. It is presumed that by gliding, the snakes are catching their preys and / or are escaping from their enemies.
4.3.5 Gliding Amphibians

Difference between Amphibians and Reptiles

Amphibians are strongly dependent on water. At the beginning of their life they are gill breathers and they always need a humid habitat to prevent drying out.

Reptiles (pp 157 – 160) are, however, pure terrestrial animals. They favor warm and sunny habitats. Their skin consists of a scale layer; some of them even have a protecting shell. During the year they moult themselves several times since their scale layer does not grow back.

Amphibians: Definition and general facts

The Amphibians are the phylogenetically oldest class of terrestrial vertebrates. Many species are living first in a larval stage in water, and after a metamorphosis they change to a terrestrial life. As a consequence of this behavior they have been named Amphibia which originates from Greek and refers to their two-stage life.

During the course of a year, the adult animals often live in aquatic habitats as well as in terrestrial habitats. The vast majority of species is dependent at least temporarily on freshwater pools. Many Amphibians are living at night, i.e. they are nocturnal animals. This protects them from natural enemies as well as from water loss through their skin.

In the above representation, the family relations within the Amphibians are illustrated. The 21 native species of Amphibians can be divided into 2 groups: the Caudates and the Batrachians. The author of this representation has indicated the number of species in parenthesis: for example, there are 5 species of Newts, 2 species of Salamanders, 2 species of Toads, 6 species of True Frogs, etc.

At the following page, the Tree Frogs are of particular interest because they are able to glide.
It is well-known that frogs are able to jump. What is much less well-known is that some frogs can fly or more precisely can glide. One member of the treefrog family which is found in Malaya can «fly». It flies not for advantage but rather to catch its prey. It is called Wallace’s Treefrog and is more equipped to chase flying insects than other frogs. It has webbed feet with long fingers and toes. When it can catch a particular insect that is flying away, it stretches its fingers and toes wide apart. This increase in surface area allows it to glide downwards for long distances. And during its decent it can catch prey for dinner.

In addition to the Wallace’s Treefrog also the Chines frog is able to glide.
4.3.6 Flying and Gliding Mammals

Flying and Gliding Mammals: Overview

- Bats and Flying foxes
- Flying Squirrels
- Colugos
- Flying Lemures
- Marsupials
4.3.6.1 Bats and flying Foxes

Bats are a group of mammals which together with the «Flying Foxes» constitute the order of bats. Flying vertebrates are divided into two groups: birds and flying mammals. From the latter, only bats and flying foxes can actively fly. Worldwide, there exist about 900 bat species. The bat shown below is the so-called «Greater mouse-eared Bat»; its wingspan is as large as 42 cm! In our latitudes, the maximum wingspan of the animals is, however, only about 8 cm.

![Greater mouse-eared Bat](image)

Anatomy of Bats

Strictly speaking, the name «Bats» (Fledermäuse) is not justified because they are by no means related to mice. Bats or «hand-fliers» represent a proper order. Together with «Flying Foxes» they are the only mammals which are capable of flight and are constituting the order of bats.

The principle type of locomotion is flying. This is possible by their flying membranes and other specific adaptations (see Figure below). There exist narrow-winged species as well as broad-winged species. The narrow-winged bats are often rapid flyers which are usually living in open areas. Their travel speed is as high as 50 km/h. On the other hand, the broad-winged bats are slow flyers (about 15 km/h) and they are moving in variegated landscapes.
In contrast to birds, bats do not have feathers. They turn their wings to the vertical axis, clap their wings upwards and then flap the flat wings downwards. The skin of the wing tails serves for manoeuvring and deceleration. Scientists of the Swedish University in Lund have studied the resulting air currents as well as how the bats are using these currents very skillfully for flying (see picture below). The secret of the acrobatic fliers can be understood on the basis of their elastic and very flexible membrane wings. The latter are functioning as a hand with skins between their fingers.

The motion of a bat's wing has been studied by researchers of the Max-Planck Institute (MPI) together with Swedish scientists. They studied the air currents in a wind channel and observed vortices generated by each stroke of wings. The arrows in the left-hand picture indicate the circular air stream; the length of an arrow indicates the velocity of the air molecules at this site. During an up-stroke of the wings, these vortices rotate at the centers of the wings as well as at the wing tips but in opposite directions. The superposition of these two vortices generates a lifting force. The photographic image has been obtained by keeping the bats at a fixed position in the wind channel while the air was flowing over the animals.

With the help of their vocal cords and of their voicebox, bats are producing hoots (inaudible calls), i.e. ultrasonic louds; this is known as ultrasonic localization. Most bat species produce these hoots by their mouth which propagate through the air as ultrasonic waves. If the sound waves impinge on an obstacle or on a pray insect, they are back reflected and the echo is detected by the bat's sensitive ears. By analyzing the echo, i.e. the frequency distribution of the sound, the sound transmitting bat can distinguish whether the reflected sound originates from a house, a tree or a pray insect. From the Doppler effect (increase or decrease of the frequency of the reflected waves), the bats are able to detect the flight direction of the pray insect (see Figure below).

White waves: Ultrasound waves emitted by the bat.

From the located object, a butterfly in the present case, ultrasonic waves are back-reflected to the bat.
Flying foxes are the largest species of bats: The wingspan of the Kalong flying fox can be as large as 170 cm and many species have a snout-vent length up to 40 cm. Many species are, however, smaller; the largest bats are distinctly taller than the smallest flying foxes.

The bodily frame of flying foxes is similar to that of bats. The membrane wings are clamped between the elongated second and fifth fingers (dactyls) and extend down to the ankles.

Flying foxes are widespread in the tropical and subtropical Africa, in southern Asia and Australia as well as in western Oceania. Similar to bats, they are essentially twilight-active and nocturnal. For searching food, they often cover large distances. During the day, they are sleeping. In contrast to bats, flying foxes are often sleeping in a hanging position at the branches of trees (s. p. 171).

In contrast to bats, flying foxes are not able to orient themselves by echolocation (an exception are the Rosette flying foxes). Flying foxes have well developed eyes as well as an excellent sense of smell. Because of the warm climate in their habitats, they are not sleeping during winter. The taller species are often assembled in large groups (up to 500'000 animals!) while the smaller species are essentially loners (rogues).

Orientation and Sleep of Flying Foxes

Orientation: The species of Pteropus of flying foxes orient themselves optically. Their twilight vision is well developed but ultrasonic location is completely absent. For the search of food, their sense of smell is very well developed. The flying foxes belonging to the species «Rousettus» are not only able to orient themselves optically but also by ultrasonic localization. Depending on the circumstances, both, optical and acoustical orientations are used. With increasing darkness, the optical orientation is replaced by acoustical orientation.

How do flying foxes sleep? During the day, they gather in large groups as sleeping colonies in high trees. There, they are hanging head over heels and envelop themselves into their leathering wings. Even the copulation of these animals takes place upside down!
Little Red Flying Foxes

PHOTO: Little Red Flying Foxes have transparent wings and red flurry bodies

Little Red Flying Foxes are tree-dwelling bats. In daytime they can be seen roosting in giant camps that may include as many as a million individuals. The bats are indeed efficient fliers, as their name suggests, but time in the trees has also made them excellent climbers.

Despite the old «blind as a bat» axiom, these and other flying foxes have excellent sense of both, sight and smell, which enables them to find plenty of their favored foods.

4.3.6.3 Flying Squirrels

Between the forelegs and the hind legs a gliding membrane is spanned up which acts as a paraglider; this enables the animal to jump from one tree branch to the other. Although squirrels are not able to fly but are rather gliding, they are referred to as «flying» squirrels.

The tail is always long, broad and bushy and serves as a flight control. Under favorable conditions, the so-called giant squirrels are able to glide over distances as large as 50 m.

In order to land at a perpendicular tree trunk below the crown, the squirrel raises the arms and the tail and is then able to tilt their body nearly perpendicularly in the air. This strongly slows down the gliding speed. In this way, the squirrel can perform a soft landing with the head upwards.
4.3.6.4 Gliding Lemurs

Flying Lemurs are not really flying but they are rather gliding through the forest over distances as large as 130 m. If they are climbing up a tree trunk, their flight membranes are folded together; this is a handicap which makes climbing particularly tedious. After having arrived at the top of the tree, they are gliding down to a branch or to another tree and the tedious ascent starts again.

Gliding Lemurs are principally nocturnal; their acrobatic flights would attract much attention to their hunters during the day.

For female Lemurs, gliding is particularly tedious since during the flight their offspring are hanging on the mother.

Remark: Gliding Lemurs should not be confused with Colugo’s (Riesengleiter: s. p. 4-A-3-5)
4.4 Gliding and Flying of Men

4.4.1 The Dream and Myth of Flying

In antiquity, flying was often considered as an attribute of privilege of the Gods. Also in cases where the Gods or the supernatural beings are not pictured with wings, their ability of flying belongs to their property. In Indian myth, there are pictures of flying divine chariots (Vimanas), as are known from the Epos of Ramayana.

One of the earliest considerations of the dream of flying of humans is found in the Legend about the Chinese Emperor Shun (2258 – 2208 BC). In this Legend, the Emperor learned to fly as a bird in order to escape from his imprisonment.

Icarus and Daedalus (Greek mythology)

Daedalus fashioned two pairs of wings out of wax and feathers for himself and his son Icarus. Daedalus tried his wings first, but before taking off from the island, warned his sun not to fly too close to the sun. Overcome by the giddiness that flying lent him, Icarus soared through the sky curiously, but in the process he came too close to the Sun which melted the wax. Icarus kept flapping his wings but soon realized that he had no feathers left and that he was only flapping his bare arms, and so Icarus fell into the Sea in the area which today bears his name, the Icarian Sea near Icaria, an Island southwest of Samos.
Berblinger: The Tailer of Ulm

Albrecht Ludwig Berblinger (1770 – 1829), known as «The Tailer of Ulm», was a German inventor and flight pioneer. He became well-known by the construction of an airworthy hang glider, with which he intended to fly over the Danube. However, the gliding flight from the «Adlerbastei» of Ulm at 1811 mislanged and he crashed into the Danube.

Before his fatal attempt, he was the first human bbeing who was able to accomplish short gliding flights. Unfortunately, his first public flight 200 years ago failed miserably. In the mean time it is evident that the daring aviation pioneer just startet from an awkward place.

It was only in the last century that Berblinger has been rehabilitated: Experts investigated the thermal conditions at the «Adlerbastei». It was found that even at the warmest weather conditions a descending air current exists over the cold water of the river. Because of the perpendicular town wall, the headwind does not develop to an upwind but rather to a whirlwind. These unfavorable wind conditions were responsible for his disaster.

Flight Pioneer Otto Lilienthal

Karl Wilhelm Otto Lilienthal (1848 – 1896) was a German engineer and flight pioneer. According to current knowledge, he was the first men who was able to complete successful and reproducible gliding flights by using hang-giders and he was able to leverage the flight principle «heavier than air».

By his experimental work he established the physical principles of airfoils which are still valid today. The production of the «Normal Glider» in his engineering works in Berlin can be regarded as the first serial production of an airplane. His principle of flying corresponds to that of the present hang-glider. This hang-glider has been further developed by the Brothers Wright to the airplane of today.

The Brothers Otto and Gustav Lilienthal have recognized that the wing form is of primary importance: They realized that slightly elevated airfoils produce a larger lift than flat airfoils. The characteristic form of the wings of birds did not slip the attention of other aerodynamic engineers too, but the Lilienthal’s have related this fact by means of exact measurements. For the evaluation of the lift they used the relation (4.1.15) quoted on our page 119. The sensational photographic pictures of flight have been reproduced in scientific and popular publications in many countries.
His brother Gustav did not participate anymore at the actual gliding flights. For this reason, the first gliding flight of a man is exclusively credited to Otto Lilienthal. It should, however, be realized that his brother actively contributed to the construction. Lilienthal constructed at least 21 gliding machines and carried out more than 2'000 flight experiments.

At August 9, 1896 he crashed from a height of 15 meters near Stöllin at the Gollenberg in Germany. Due to awkward thermal conditions, Lilienthal's glide pitched forward heading down quickly. One reason for his accident is probably also related to the fact that he always tried to increase the flight distance. He died either from a cervical fracture or from a brain bleeding.

**4.4.2 The first gliding and flying machines**

The brothers Wright, Wilbur Wright (1867–1912) and Orville Wright (1871–1948) from Dayton, Ohio, were American pioneers of aviation. At the beginning of the 20. century, they performed first flights with gliders and then they started flights with motor-controlled airplanes.

Following Lilienthal, the brothers Wright used the lift relation (in this work: equation 4.1.15, p. 119) but with a modified coefficient $C_A$. They also recognized that Lilienthal's crash was due to inadequate flight control (steering capability).

At 1899 the brothers Wright started with the construction of the first flying machine, a biplane gliding flyer (see photograph). It contains already a very important feature, namely the wing-warping airfoils, with which the horizontal position of the flight apparatus could be controlled.

Between 1901 and 1903, many unmanned and manned gliding flights have been performed. During the year 1902 a large number (more than 1'000) gliding flights with the biplane glider were carried out, the longest distance was $s=189.7$ m with a flight duration of $t=26$ s, i.e. the mean velocity was $v=s/t = 7.3$ m/s $= 26.2$ km/h.
Double decker motorized Airplane

At December 17, 1903 Orville and Wilbur Wright started their «Flyer». It was a fragile looking Double decker motorized airplane built from wood, wire and textile.

The brothers cut a propeller having a high efficiency and gave order to manufacture a suitable propulsion unit, namely a water-cooled four-cylinder four-stroke gasoline engine having a mass of 81 kg which delivered 12 PS. For momentum compensation, the airplane was equipped with two opposite air-screws having a suitable mechanical drive.

The motorized airplane was 12 seconds in the air and covered a distance of 37 meters, corresponding to an average velocity of 11.1 km/h. The velocity could be increased to 16 km/h. The airplane had a wingspan of 12.3 m; its length was 6.4 m and its height was 2.8 m. The flight mass was 340 kg and the pilot was laying quitely at the lower airfoil.

Charles Lindbergh : Alone over the Atlantic

Charles Lindbergh (1902 – 1974) was an US pilot and winner of the «Medal of Honor». Between March 19 to 21 he was able to achieve the first Solo Flight over the Atlantic, starting in New York and landing in Paris. The covered distance was 5’805.5 km, for which he needed a flight time of 33.5 hours. His airplane had only one single motor with a power of 223 PS. The average speed was 173 km/h, and the maximum speed was 220 km/h.

In the benefit of a maximum fuel load, Lindbergh did not carry with him neither a radio equipment nor a sextant. He was only equipped with a wristwatch and a compass. The most severe problem was a heavy snow storm in Newfoundland which he passed between New York and Nova Scotia. Another severe problem was to overcome his fatigue during his flight between Southern Island and Southern England. However, his navigation worked very well: when he atteined the shore of Ireland, he was only 5 km off from his target. He than flew along the coast of England, passed the English Channel and arrived in France. In Paris he was received by a jubilant crowed.
4.4.3 The Airship of Count Ferdinand Von Zeppelin

The principle of the Airship is simple: It is filled with a gas which is lighter than air thereby gaining a lift and is gliding forward, powered by motor-driven propellers.

The largest Zeppelin which has ever been built was the giant Airship LZ 129 «Hindenburg». Its length was 245 m(!), its maximum diameter was 41.2 m and it was filled with 200'000 m$^3$ Hydrogen. Instead of hydrogen it is also possible to use the inert Helium gas. The LZ 129 was equipped with 4 Diesel engines (total power 4'200 PS, maximum velocity 130 km/h, travelling time from Frankfurt to New York: 2 ½ - 3 days). Its last flight took place in May 1937. During landing at Lakehurst near New York, the Hindenburg caught fire and burst into flames within seconds. At the time of this Hindenburg disaster, 97 persons were on board, but 62 of them survived the catastrophe.

4.4.4 The Sailplane

A sailplane is an aircraft which is constructed for gliding with a small loss of altitude. In the upwind it even rises. In order to be able to fly, it must transform height (potential energy) into forward speed (kinetic energy). A sailplane must be started appropriately. Starting can be achieved by using an aircraft tractor (s. left-hand Figure below). The sailplane is raised into the air by means of a motorized aircraft. The height at which the sailplane is released is usually between 500 m und 1500 m. There exist also other starting principles (s. Reference R.4.4.7).

Modern sailplanes have a gliding ratio between 1:30 and 1:60. This means that in quiete air they can fly 30 to 60 km with a loss of height of only 1 km. In order to achieve good gliding properties, a sailplane must be constructed with a very low drag.
4.4.5 Jet engines of Airplanes

The propulsion of a Jet Aircraft (e.g. Boeing 747) depends on the reaction propulsion: A rapid ejection of a combustion gas creates a recoil in the opposite direction. Therefore, if a jet engine ejects a jet blast in the backward direction, a recoil in the forward direction is created. As a consequence, the whole Jet aircraft is accelerated in the forward direction.

[As we have discussed at p. 4-A-2-3, Octopus are using the same principle, the principle of conservation of momentum to escape the water and to glide through the air.]

Some Data of Boeing 747 - 81

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>76.30 m</td>
</tr>
<tr>
<td>Wingspan</td>
<td>68.50 m</td>
</tr>
<tr>
<td>Airfoil area</td>
<td>534 m²</td>
</tr>
<tr>
<td>Span width</td>
<td>22.17 m</td>
</tr>
<tr>
<td>Height</td>
<td>19.40 m</td>
</tr>
<tr>
<td>Fuselage height (Rumpfhöhe)</td>
<td>7.85 m</td>
</tr>
<tr>
<td>Cabin width (internal)</td>
<td>6.1 m</td>
</tr>
<tr>
<td>Cabin height</td>
<td>2.54 m</td>
</tr>
<tr>
<td>Flying range</td>
<td>14'815 km</td>
</tr>
<tr>
<td>Speed at an altitude of about 10'700 m</td>
<td>913 km/h</td>
</tr>
<tr>
<td>Take-off speed</td>
<td>~ 300 km/h (*)</td>
</tr>
<tr>
<td>Maximum take-off mass</td>
<td>447'700 kg</td>
</tr>
<tr>
<td>Maximum number of seats</td>
<td>605</td>
</tr>
<tr>
<td>Average number of seats</td>
<td>467</td>
</tr>
<tr>
<td>Crew (Cockpit)</td>
<td>2</td>
</tr>
<tr>
<td>Aircraft delivery</td>
<td>2013 - 2015</td>
</tr>
<tr>
<td>Number of orders at 2013:</td>
<td>~ 33</td>
</tr>
<tr>
<td>(*) depending on take-off weight, height of runway and weather.</td>
<td></td>
</tr>
</tbody>
</table>

Airbreathing Jet Engine

The airbreathing engine suckes in the ambient air and increases its pressure in a compressor. In the adjacent combustion chamber, the fuel (Kerosine) is injected and the mixture is combusted. The combustion increases the temperature and the flow speed of the gas. This flow energy is partially transformed into rotating motion of the turbine and the gas is further expanded (thus the turbine extracts energy).

The turbine powers the compressor, the fan and other aggregates. The gas expands in the thrust nozzle behind the turbine and acquires nearly ambient temperature while the flow speed is further increased. The gas escaping through the thrust nozzle generates the propulsion (recoil) in the opposite direction. (For more information see Appendix 4-A-4-1).
4.4.6 The Helicopter - General

A Helicopter is a vertically starting and landing aircraft. It transfers motor force to one or several rotors for generation of lift and thrust. These rotors are rotating wings; for this reason, Helicopters are rotating-wing aircrafts.

The splitting of the incoming air at the rotor blades gives rise to a pressure difference and a corresponding dynamical lift (see pp 114, 117 for fixed wings). As for the case of airplanes, the lift depends on the profile of the wing, on the angle of attack and on the flow speed of the air.

The basic physical flight principles are therefore the same as for a fixed-wing airplane. For a Helicopter, however, the wings are rotating around the rotor shaft. As a consequence, a Helicopter is more flexible than an airplane, it can even hovering at a fixed position.

The flying of an airplane can be explained by the recoil principle: The dynamics of the air around an airfoil results in a lift force. For a Helicopter, a lift force exits even if the wings are rotating at a fixed position.
The spinning rotor blades of a Helicopter accelerate the air from top to bottom. This increases the angle of attack $\alpha$. (The angle of attack is the angle between the relative direction of air flow and the chord line of the rotor blade). In analogy to a fan, the air is blown downward, the lift is increased and the Helicopter starts to ascend. In order that the Helicopter is moving forward, the rotor plane must be tilted forward; in this way, the airstream is blown backward by the rotor blades.

(See also the similarities and differences with the flight characteristics of Dragonflies (pp 138, 139).

According to the law of action and reaction, the trunk of the Helicopter is turned in the opposite direction to that of the rotor. In order to prevent this, most Helicopters are equipped with a perpendicularly oriented rotor, the so-called tail rotor, which balances this torque. With the help of this tail rotor, the Helicopter can also be navigated around its vertical axis in the case of a hovering flight.

Helicopters with two main rotors spinning in opposite directions, do not generate a resulting torque but the lift is then reduced.
Basic Equations of Aerodynamics

Navier – Stokes Equations

The Navier–Stokes equations are the fundamental relations for viscous heat-conducting fluids (gases, liquids). They consist of a system of coupled non-linear differential equations, which have been derived by applying Newton’s equations of motion to a fluid-element. These equations are very complex and can only be solved numerically.

Euler’s – Equations

The Euler-equations are a system of partial differential equations of first order which is a special case of the Navier-Stokes equations if frictional forces (viscosity) and heat conduction can be neglected. Euler’s equations are usually also solved numerically.

The Bernoulli Equation

For the case of stationary flows, Euler’s equations can be spatially integrated and one obtains the Bernoulli-equation which is valid for the entire fluid current. In the special case of incompressible homogeneous fluids with constant density $\rho$ and if only the gravitational force is acting, one obtains:

$$p + \rho g z + \frac{1}{2} \rho u^2 = p_0 = \text{const.}$$

Here, $p$ is the hydrostatic pressure, $p_0$ the total pressure, $\rho$ the density of the fluid (air), $u$ the velocity of the moving object or of the fluid. The term $(1/2)\rho u^2$ is the hydrodynamic pressure, $g$ is the gravitational acceleration and $z$ is a reference level with constant geodetic altitude (pp 4-A-1-3, 4-A-1-4).
Forces acting on a fluid particle along a streamline

Stationary current along a streamline \( s(x,z) \)

\[ \frac{dV}{dA} = \text{volume element} \]

\[ p = \text{pressure}; \quad p\,dA = \text{force} \]

\[ dm = \text{mass contained in volume element } dV \]

\[ g = \text{gravitational acceleration} \]

\[ dG = \text{weight} = g \, dm \text{ in } dV \]

\[ u = \text{velocity of } dm \]

\[ a = \text{acceleration of } dm \]

\[ F_N = dm \, a = \text{Newton's force acting on } dm \]

Derivation of Bernoulli's equation

Let \( dm \) be the mass in the volume element \( dV = dA \, ds \) of the streamline considered (s. Figure, p. 4-A-1-2). If \( u(s) = ds/dt \) is the velocity of \( dm \), the acceleration \( a \) of \( dm \) is given by

\[ a = \frac{du}{ds} \quad (\text{ds}/dt = u \, (du/\text{ds}) ) \quad (1) \]

and Newton's force is

\[ F_N = dm \, a = dm \, u \, (du/\text{ds}) \quad . \quad (2) \]

Let \( dV = dA \, ds \) be the volume element considered and \( \rho = dm/dV \) the density of the fluid at the position \( s \). For an isothermal fluid with negligible friction, the external forces \( F_{\text{ext}} \) are composed on the pressure forces and the weight force \( dG \): From the Figure on p. 4-A-1-2 it follows:

\[ F_{\text{ext}} = p \, dA - (p + dp) \, dA - dG \sin(\theta). \quad \text{With } F_{\text{ext}} = F_N \text{ we obtain} \]

\[ p \, dA - (p + dp) \, dA - dG \sin(\theta) = dm \, u \, (du/\text{ds}) \quad (3) \]

Using \( dG = g \, dm \), \( dm = \rho \, dV = \rho \, dA \, ds \) and with \( \sin(\theta) = dz/\text{ds} \) it follows

\[ dG \sin(\theta) = \rho \, g \, dA \, ds \, (dz/\text{ds}) \quad (4) \]

Substituting eq. (4) into eq. (3) and using \( u \, du = (1/2) \, d(u^2) \) one obtains after simplifying

\[ dp + (1/2) \, \rho \, d(u^2) + \rho \, g \, dz = 0 \quad (5) \]

If \( \rho \) is independent on \( p \) (incompressible fluid), one obtains after integration Bernoulli's equation:

\[ p + (1/2) \, \rho \, u^2 + \rho \, g \, z = \text{const.} \quad (6) \]

or

\[ p_1 + (1/2) \, \rho \, u_1^2 + \rho \, g \, z_1 = p_2 + (1/2) \, \rho \, u_2^2 + \rho \, g \, z_2 \quad (6a) \]

4 – 46
Due to a superposition of the starting vortex, the circulation vortex $G$ around the wings and the air stream $u_\infty$, the airfoil streaming is established and as a consequence, the dynamic lift starts to operate. According to the conservation of angular momentum, the circulation flow $G$ and the starting vortex cancel each other; the same holds for the tip vortices of the two wings. Note also the elliptic distribution of the dynamic lift $F_A$ across the two wings.
Re = 10⁴: Larger insects such as dragonflies and hawk moths are flying with Re- numbers of ≈ 10⁴.

Re between 10⁴ and 10⁵: Most of the medium-sized insects are flying in this range.

Re smaller than 10²: The great army of small insects who are weighing only a few milligrams are flying with Re- numbers in the teens (not shown in the diagram). The flight of these animals is dominated by viscous resistance forces. W. Nachtigall, a pioneer of animal flight has formulated the situation of these tiny little things vividly as follows: “For these tiny insects the air behaves as a tenacious honey in which they are floundering about as water flies.”

Example: Fairyflies are the smallest insects known; the males of the species «Dicopomorpha echmepe-rigyis» have a length of only 0.14 mm. With their paddle shaped reduced forewings they are not good fliers but are rather carried by the wind. In the following we assume that they are flying in completely still air and we estimate their Reynolds number Re (s. p. 127). We put L = 0.2 mm (female); p = 1.204 kg/m³ (density of air at 20°C); η = 18 x 10⁻⁶ kg m⁻¹ s⁻¹; u = 1 cm/s = 0.01 m/s. It then follows: Re = 1.

Octopuses belong to invertebrate molluses; they are cephalopods with 8 to 10 arms. Without exception their predators (Räuber) and most of them are very fast swimmers. Calamaries and Common Octopuses are subgroups of Octopuses; Calamaries and Common Octopuses (Kraken) have 10 and 8 arms, respectively. On the run in water, they employ the principle of recoil: they press out the water from their mantle cavity through a sinkhole and escape by the principle of recoil.

Based on this propulsion technology, some species are able to escape from the water and are then able to glide 30 to 50 meters in the air above the water surface. Based on the jet propulsion, they are able to achieve velocities up to 11.2 meters per second ! The Figure shows that during the gliding, the Octopuses are adopting an aerodynamically efficient shape. They use gliding while hunting crustaceans or gastropods or to escape predators.
Bird Migration

Bird migration is referred to as the annual flight of migrating birds from their breeding area to their winter quarter and back again to their breeding area.

The ecological origin lies in the extreme seasonal variations of the food availability in the breeding grounds. As insect eaters, they do not find insects and as a consequence, large bird populations would die during winter due to lack of food.

Genetic and physiological origins: Whether a bird migrates, where it migrates and when it migrates is determined genetically. Both, the direction of flight as well as the flight duration are inherent.

Orientation: The internal compass is presumably due to the existence of magnetic field recorders in the eye, which enables the birds to determine the tilt angle of the Earth’s magnetic field. In addition, birds are able to guide themselves with the help of the starry sky. The birds can also determine the position of the Sun in the case of a cloudy sky by detecting the UV radiation emitted by the Sun.

Bird migration metabolism: Nutrition is saved before migrating. They even resort to the proteins of their internal organs.
Migrating birds: Starlings in Flight to their Winter Habitats

Alpine swift - World record in endurance Flight

From time to time, even birds must land for feeding and for recovering. One exception are swifts who are perfectly adapted to the life in the air. They feed by catching insects in flight. It has long been suspected, that they do not sleep at night, but rather stay in the air all night long. The best indication for these uninterrupted flights have been obtained from Radar Images of the Common swift in large altitudes (right-hand picture). Recently, scientists of the Swiss Ornithological Station in Sempach, Switzerland, have demonstrated that the closely related Alpine swift (left-hand picture) is able to remain more than 6 months continuously in the air. In 2011, researchers of this Institution have equipped Alpine swifts with «Geolocators». This has been done in collaboration with the University of Applied Science in Burgdorf (Bern). The Geolocator is a technical masterpiece having a weight of only 1 g. All year round, this instrument measures and stores the brightness in the vicinity of the bird. From these data it is then possible to measure the day length from which the geographical position of the bird can be determined. The instrument is also able to give information regarding the dynamics of the wings (durations of flapping and gliding motions, respectively). With the Geolocator mounted on the back of the Alpine swifts, the birds flew into their winter quarters (usually in Africa) where they spent the cold season, and in spring they returned to Switzerland. The unique instrument demonstrated that the birds remained non-stop in the air all the time of flight to Africa, as well as during the time spent in their winter habitats.
Colugo’s (Riesengleiter)

Colugo’s have about the size of a cat but they are built distinctly lighter. Depending on the species, their total length is 56 to 69 cm and their snout-vent length varies between 34 and 42 cm. Mass: 1 to 1.74 kg; wingspan: 70 to 120 cm. Colugo’s are living in Southeast Asia.

The gliding animal has a flying membrane which covers almost the whole body and extends down to the spiky claws. By spreading the forelimbs and the hindlimbs, the animal is able to open the thin flying membrane similar to a parachute. But the membrane is immobile and for this reason, the Colugo is not an active flyer but rather a glider.

Colugo’s are essentially nocturnal tree-dwellers and descend seldomly to the ground. During the day, they are living in tree holes or on tree branches as well as on tree trunks and are found at heights between 25 and 50 meters above ground. It is only after the beginning of darkness when they start to be active. Their gliding flight varies between 50 and 70 meters, in exceptional cases up to 136 meters.

Alfred Hitchcock - The Birds

The overriding question is why are birds attacking? The reason is humanitie’s long history of killing birds and other animals. Therefore, humans are now suddenly the victims of bird attack.

«The Birds» implies that the avian assaults are nature’s revenge on complacent and willfully ignorant humanity.
The sucking in of air takes place in the part where the air of mass $m$ and velocity $v_{\text{in}}$ streams into the engine. $m \cdot v_{\text{in}}$ is the momentum of inflowing air.

The air is compressed by a compressor, which is driven by the turbine.

Combustion is achieved by adding a fuel (Kerosine) into the combustion chamber.

The discharged air with velocity $v_{\text{out}}$ takes place in the turbine compartment and in the thrust nozzle. Note that $v_{\text{out}} \gg v_{\text{in}}$; $m \cdot v_{\text{out}}$ is the momentum of the outflowing air.

For more detailed information see Ref. R.A.4.1.
Referenzen: Kapitel 4

### 4.0 Flying - Overview

R.4.0.1 p. 107: Flying and Gliding: Overvies; (collected by P. Brüesch)

R.4.0.2 p. 108: Flying and Gliding of Birds and Airplanes:


c) Flying White Stork and Boeing 747 - 100
   - Flying White Stork: Text from: Whight stork - Pictures from: Google Images

### 4.1 Physical Basis

R.4.1.1 p. 110: Physics of Flying - Aerodynamics

a) Overview about Navier-Stokes – Euler – Bernoulli – and Kutta-Joukowski – equations (P. Brüesch)

b) Navier-Stokes Equations - From Wikipedia, the free encyclopedia

c) An Introduction to Fluid Dynamics - G.K. Bachelor - Cambridge University Press /2000)

d) Die physikalischen Grundlagen der Luftfahrt - Lena Michaela Altherr
   - Johannes Gutenberg-Universität Mainz - Institut für Physik
   - [www.zq.uni-mainz.de/.../Die_physikalischen_Grundlagen_der_Luftfahrt](http://www.zq.uni-mainz.de/.../Die_physikalischen_Grundlagen_der_Luftfahrt)

R.4.1.2 p. 111: Air flow acting on an airfoil

a) Aerodynamics - [http://en.wikipedia.org/wiki/Aerodynamics](http://en.wikipedia.org/wiki/Aerodynamics) (contains Figure of airfoil)


f) Flying of Birds – The Flying Birds – Animal Wallpaper
   (found under «Flying of Birds» - Forces on a wing added by P. Brüesch)
R.4.1.3 Euler – Equation

a) Euler equation (fluid dynamics) - http://en.wikipedia.org/wiki/Euler_equations_(fluid_dynamics)

R.4.1.4 Theorem of Kutta-Joukowski

b) Introduction to Hydrodynamics - Hardy Peter and Rolf Schlittenberger: Vorlesungen an der Universität Freiburg (2004 / 2005); written in English
www.kis.uni-Freiburg.de/~schlichen/…/hydro.pdf
d) Das Gesetz von Kutta-Joukowski
http://www.physik.uni-wuertzburg.de/video2/alpha/kap5/Tips/Tip01/Tip01_ct.htm

R.4.1.5 Bernoulli equation and Theorem of Kutta-Joukowski

a) Lift: Why can airplanis fly? (PDF : Chapter 5) Hardi Peter und Rolf Schlittenberger: Introduction to Hydrodynamics
www3.kis.uni-Freiburg.de/~schlichen/…/hydro.pdf
c) Fliegen und Luftfahrt (Flying and Aeronautics) [PDF] Script: www.phys.uni-heidelberg.de/…/huefner/V075.p-…
d) Wie erklärt man das Fliegen eines Flugzeuges? (How can the flying of an aircraft be explained?) Rita Wodzinski: seriendblogs.de/daxx/…/warum-ein-flugzeug-fliegt… PLIS LUCIS (Fachdidaktik) pp 18 – 22
e) Wie erklärt man den Auftrieb nach Kutta-Joukowski? (How can the lift be explained on the basis of Kutta Joukowski?)
Heuristische Herleitung der Kutta-Joukowski Gleichung aus der Bernoulli-Gleichung (for thin planar plates) – Heuristic derivation of Kutta Joukowsky from, Bernoulli’s equation
http://www.physik.uni-wuertzburg.de/video/alpha/kap5/Tips/Tip05/Tip05_ct.htm

R.4-2

R.4.1.6 p. 112: The Bernoulli equation

a) Derivation and Interpretation of Bernoulli’s equation - Lesson 61: Physics – Trinity Valley School Dr. Mitch Hoselton; Physics: An Incremental Development, John H. Saxxon, Jr. faculty.trinityvalleycollege.org/…/Lesson%261
c) Bernoulli-Gleichung; Druckerhaltung und Energieerhaltung [PDF] Bernoulli-Gleichung - www.delta-a.de/export/…/beroulligleichung.pdf;
This equation can be derived from Energy conservation or directly from Newton’s second Law. The derivation given in the Appendix (pp 4-A-1-2 and 4-A-1-3) is based on Newton’s Law (linear momentum equation of Fluid Dynamics)
highered.mcraw-hill.com/…/Simple_Chapter.pdf; - Chapter 12f) Bernoulli’s or Newton’s Laws? - http://hyperphysics.phys-astr.gsu.edu/hbase/fluids/airfoil.html
contains a Section about «Airfoil Terminology»

R.4.1.7 p. 113: Air flow around Airfoil - 1:

a) First and third Figure from: «Das Gesetz von Kutta-Joukowski» http://www.physik.uni-wuerzburg.de/video2/alpha/…/FluidDynamik/node25ct.html
b) Second Figure from: BoundVortex - http://www.boundvortex.com/Read/Article.aspx?ArticleID=53
c) Airfoil: http://en.wikipedia.org/wiki/Airfoil

R.4.1.8 p. 114: Air flow around Airfoil - 2:

b) Airfoils and Airfoil: http://www.avlin.com/how/htm/airfoils.htm
(Conclusion: Bernoulli’s principle is an excellent approximation under a wide range of conditions)
(Contains a discussion of the applicability of Bernoulli’s equation – pro and contra)
(contains the Figure showing the «Potential flow», the «circulation» and the «resulting streamlines»
e) see also References R.4.1.1 d) quoted on p. R-4-1

R.4-3
4.2 Flying and gliding Invertebrates

4.2.1 Invertebrates and Vertebrates

R.4.2.1 p. 121: General Remarks
Flying and gliding animals - [http://en.wikipedia.org/wiki/Flying_and_gliding_animals](http://en.wikipedia.org/wiki/Flying_and_gliding_animals)

R.4.2.2 p. 122: Flying in the geological time scale
a) Geological Time Scale
(contains Table of biological – geological time scale)

R.4.2.3 p. 123: The Planet of Insects
d) Planet der Insekten - [http://www.schmetterlingspark.de/insekten.htm](http://www.schmetterlingspark.de/insekten.htm)
(The Figure has been adapted to English by P. Brüesch)

4.2.2 Flying and Gliding Invertebrates: Insects

R.4.2.4 p. 124 Flying and Gliding Invertebrates (Title)

R.4.2.5 p. 125: Definition: What are Insects?
a) see References R.4.2.3
b) Insekten - [http://de.wikipedia.org/wiki/Insekten](http://de.wikipedia.org/wiki/Insekten)
  d) Lebenszyklus der Schmetterlinge  
  Picture from: http://www.telfs.com/noafl/schmetterlingspage/frames/Lebenszyklus.htm  
  (Labeling of the Figure translated from German to English by P. Brüesch)

R.4-2.13  p. 133: Wings and Flight Characteristics of Butterflies  
  b) Flight Behavior: How To Estimate The Altitude of Migrating Butterflies - http://www.erin.utoronto.ca/~w3gibo/Hpw%20to%20d%20field%20studies/flight_behavior.htm

The author is indebted to Mister Peter Etter for his information about the Dicopomorpha echmepterygis
4.2.4 Files and Gnats

R.4.2.15 p. 135: Flight of Flies and Gnats
c) Wie fliegen Fliegen ? - http://www.mpg.de/3648523/Wie_Fliegen_fliegen

R.4.2.16 p. 136: Mosquitos
b) Malaria - http://simple.wikipedia.org/wiki/Malaria
c) Mosquitos Born Diseases - http://www.mosquito.org/mosquito borne diseases
d) Mücken - http://de.wikipedia.org/wiki/M%C3%BCcken
(e) Stechmücken - http://de.wikipedia.org/wiki/Stechm%C3%BCcken

4.2.5 Hymenoptera (Hauflügler)

R.4.2.17 p. 137: Hymenoptera (Hauflügler)
d) Hautflügler - http://de.wikipedia.org/wiki/Haut%C3%BCgler
(e) Xyelidae - http://de.wikipedia.org/wiki/Xyelidae - Picture - right]

4.2.6 Dragonflies

R.4.2.18 p. 138: Dragonflies
b) 10 - Fascinating Facts About Dragonflies http://insects.about.com/od/dragonfliesanddamselflies/a/10_Cool_Facts_About_Dragonflies.htm
d) Libellen - http://de.wikipedia.org/wiki/Libell
(e) Fliegen Libellen anders als andere Insekten - wissen.de http://www.wissen.de/bikdwh/fliegen-libellen-anders-als-andere-Insekten
4.3 Flying and Gliding Vertebrates (p. 140)

4.3.1 Pterosaurs (p. 141)

4.3.2 Birds: Physiology, History – Flight Dynamics and Examples

4.3.7 p. 146: Birds: History, Masters of the Air – Examples

b) Bird flight: http://wikipedia.ru/wiki/Bird#flight

4.3.8: p. 146: Referat: Evolution der Vögel
http://www.pausenhof.de/referat/biologie.evolution-der-vogel/9952
Text zu p. 146 (Translated from German to English by P. Brüesch)

4.3.9 p. 147: Habitus and Skeleton of a Bird

a) Skelett, Körperbau und Organe eines Vogels (left-hand picture)
http://www.medienwerkstatt.online.de/wes_wissen/vorlagen/showcard.php?id=5194
b) The Skeleton of a Typical Bird (right-hand picture)

4.3.10 p. 148: Physiology of Birds: Skeleton - Physiologie der Vögel: Skelett

a) Longitudinal section: from www.google.ch/search - Bilder
b) Cross section: Faszination Fliegen – Modell Vogel
http://its.mv.fh-duesseldorf.de/Vorlesung/alt_iplom_schueler_etc/facharbeiten/quirimus/CD_facharbeit_Tragfluegel

4.3.11 p. 149: Physiology of Birds - The wings

b) Bird Feather Types, Anatomy, Growth, Color, and Molling
http://peteduction.com/article.cfm?o=15x18298&aid=2776
c) Feather Structure - http://www.birds.cornell.edu/All/AboutBirds/studyinf/feathers/feathers
d) Bird Feather Identification -
f) Wie fliegt ein Vogel? -
http://129.143.239.62/lecker/biologie/klasse06/vogelflug/vogelflug.htm
(contains microscopic picture of feathers)
g) Flügel (Vögel) - http://de.wikipedia.org/wiki/F1%C3%BctigVogel
h) VogelFügel - http://universal.feron.de academoc.com/316312/Vogelf%3C%3B}
4.3.12 p. 150: Dynamics of the Flying of Birds

b) [PDF] How Do Birds Fly? - [files.dir.state.mn.us/publications/volunteer/you](files.dir.state.mn.us/publications/volunteer/you)
e) Das Flugprinzip der Ornithopter - [http://www.ornithopter.de/ptinzip.htm](http://www.ornithopter.de/ptinzip.htm)

4.3.13 p. 151: Records of Bird Migration

c) List of High Flying Birds - [http://animals.pawnonation.com/list-high-flying-birds-9333.html](http://animals.pawnonation.com/list-high-flying-birds-9333.html)
h) Der Alpensegler: Weltrekord im Dauerfliegen - Dr. Felix Liechti (Schweizerische Vogelwarte Sempach) - [http://www.xn-vgat-5og.c/weltrekord-im-duerfliegen.html](http://www.xn-vgat-5og.c/weltrekord-im-duerfliegen.html)

4.3.14 p. 152: Examples of colorful Birds - from Wikipedia - Images

4.3.15 p. 153: Andean condor

b) Andean Condor - [http://animals.nationalgeographic.com/animals/birds/andean-condor/](http://animals.nationalgeographic.com/animals/birds/andean-condor/)
c) Andenkondor - [http://de.wikipedia.org/wiki/Andenkondor](http://de.wikipedia.org/wiki/Andenkondor)

Bild: unter [www.google.ch](http://www.google.ch) »Vogelflug«: Aktivitäten 2002 – uzwil.birdlife.ch

4.3.16 pp 154, 155: Gliding fishes

   Picture for p. 154 unter Images: [www.google.ch/search](http://www.google.ch/search) - (File: Pink-wing flying fish.jp-Wikipedia)
b) Flying Fish: [http://animals.nationalgeographic.com/animals/fish/flying-fish/](http://animals.nationalgeographic.com/animals/fish/flying-fish/)

R.4.3.17 p. 156: Sharks and flying flights of Sharks (Pictures from Google – Images)


4.3.18 p. 157: Reptiles

c) Reptiles: Lizards, Snakes, and Others - [http://www.kidport.com/repflb/science/animals/reptiles.htm](http://www.kidport.com/repflb/science/animals/reptiles.htm)
d) Animals / REPTILES - [http://animals.sandiegozoo.org/content/reptiles](http://animals.sandiegozoo.org/content/reptiles)

R.4.3.19 p. 158: Flying Dragons

   Flying Dragon: Lizards: Animal: Olanet
   Picture from: [www.google.ch/search](http://www.google.ch/search) - Images: Flying Dragon: Lizards: Animal: Olanet

4 – 59
R.4.3.20 p. 159: Gliding Flight of Geckos
a) Picture of Gecko - SCIENCE PHOTO LIBRARY
   Flying Gecko - http://www.sciencephoto.com/media/379134/view
b) Facts about the Flying Gecko’s Natural Habitat
c) Geckos: http://de.wikipedia.org/wiki/Gekkos
d) Von Baum zu Baum segeln - Wirbeltiere lernen fliegen - Fluggeckos
   http://www.dasert.de/information/wissen-kultur/w-wie-wissen/specials-von-baum-zu-baum-segeln-100.htm
e) Gleitflug bei Tieren
   http://www.wissen.dethema/gleitflug-bei-tieren/?chunk=gleitflug-bei-amphibien-und-reptilien

R.4.3.21 p. 160: Gliding Snakes
a) Fliegender (gleitender) Schlangen
   http://www.focus.de/wissen/natur/biologie-fliegender-schlangen_aid_574578.html
b) s. auch Ref. R.4.3.20 c)

4.3.5 Gliding Amphibians

R.4.3.22 p. 161: Amphibians - Gliding Amphibians

R.4.3.23 p. 162: Amphibia (Lurche)
Die 21 mitteleuropäischen Amphibien und ihre wesentlichen Bestimmungsmerkmale – BioNetworX.de
http://www.bionetworx.de/biomemorix/uebersicht.html
Contains Diagram of «Amphibia (Lurche)
(Names of Amphibia in Diagram and Text translated from German to English by P. Brüesch)

R-4-14

R.4.3.24 p. 163: Gliding Frogs
a) Flying and gliding animals - http://en.wikipedia.org/wiki/Flying_and_gliding_animals
c) Wallace’s flying frog - http://en.wikipedia.org/Wallace’s_flyingfrog
e) Picture and Text found under: »Flying frogs« – Images
   Collection & Selection: Earth Facts to visit page - Flying frog : Wallace’s Treefrog
f) Vergleichende Tierphysiologie – Vol. 1, p. 627
   Gerhard Heldmaier, und Gerhard Neuweller – 2003 - Science books.google.ch/books?isbn=3540442839
   http://books.google.ch/books?id=rKx-RKYoxeMC&pg=PA627&dq=Sprungweite+von+Frogs+von+F%C3%B6sch

4.3.6 Flying and Gliding Mammals

R.4.3.25 pp 164, 165: Flying and Gliding Mammals - Overview
Bats - Flying Foxes - Colugos - Marsupials - Lemures - Flying Squirrels - Information from different sources

R.4.3.26 pp 166: 4.3.6.1 : Bats and flying Foxes

R.4.3.27 pp 166 - 169: Bats
b) Bats in Flight Reveal Unexpected Aerodynamics
   http://www.freerepublic.com/focus/s-news/1771906/posts
c) Bats in Flight Reveal Unexpected Aerodynamics
   http://www.brown.edu/Administration/News_Bureau/2006-07-06-082.html
d) Bat Flight Generates Complex Aerodynamic Tracks

R-4-15

4 – 60
R.4.3.28 pp. 166 – 167: Fledermäuse (Bads)
a) p. 166: Arbeitsgemeinschaft für Fledermäuse – Fulda e.V.
   Figure from Reference R.4.3.27 e)

R.4.3.29 pp 167-168: Flugtechnik : Fledermäuse im Windkanal
a) Fledermäuse schiessen im Flug schnell nach oben – ORF ON Science
c) p. 168: [PDF] Fledermäuse sorgen für Wirbel
   Figur: Momentaufnahme der Luftströmung um eine Fledermaus im Windkanal
   Figure: Photograph of air stream with vortices produced by a bat in the Wind Channel
   www.mpg.de/933912/S007_Blickpunkt_092.pdf

R.4.3.30 p. 169: Landfachausschuss für Fledermausschutz und Forschung: Fledermäuse hören ihre Umgebung
http://www.lfa-fledermausschutzmv.de/Deeortung19.0.html (s. auch Ref. R.4.3.26, p.166)
   Contains Figure of «Braunes Langohr beim Orteneines Falter»
   i.e. Figure of «Echolocation of Bats»

R.4.3.31 p. 170-172: Flying Foxes - Flughunde
c) Flughunde - http://de.wikipedia.org/wiki/Flughunde
   Figure 34: Figure 4: Flughunde
   Figure: Flughunde
   http://de.wikipedia.org/wiki/Eigentliche_Flughunde

d) Orientierung und Schlaf der Flughunde
http://de.wikipedia.org/wiki/Lemuren
http://www.feous.de/artikel/details/fledermeuse

R.4.3.32 d) Flughunde fliegen nach der Karte

R.4.3.33 p. 172: Little Red Flying Fox
a) Little Red Flying Fox - http://animals.nationalgeographic.com/animals/mammals/little-red-flying-fox/
b) Flying foxes make unusual sojourn to the Barkly
   www.abc.net.au/news/2012-10-12/-/flying-foxes-at-4310686
   By Ruby Jones - contains PHOTO of «Little Flying Foxes»
c) Little red flying fox - http://en.wikipedia.org/wiki/Little_red_flying_fox
   Figure 34: Figure 4: Flughunde
   Figure: Flughunde
   http://de.wikipedia.org/wiki/Lotrer_Flughund

d) Befliegen der Flughunde (Gleithörnchen)
http://en.wikipedia.org/wiki/Flying_squirrel
http://de.wikipedia.org/wiki/Gleith%C3%Bcnchen

R.4.3.34 p. 174: 4.3.6.3 - Gliding Lemures
b) Why do flying lemurs glide?

   Why do flying lemurs glide?
4.4 Flight Attempts and the Flying of Men

R.4.4.1 p. 176: The Dream and Myth of Flying

c) Geschichte des Fliegens – Die Anfänge bis zum ersten Weltkrieg
http://www.luftrettung-hamburg.de/html/pionierse.html
d) A History of Aeronautics
g) Shun (Kaiser) - http://de.wikipedia.org/wiki/Shun_(Kaiser)
h) Schwerelos, Kai König - http://www.heise.de/o/artikel/Schwerelos_506840.html
l) Daedalus and Icarus - (with right-hand picture below)
http://www._RF_Overlake.org/Academics/Faculty/jrothfels/Latin%2011%20Wid%202007/hades/index.html

R.4.4.2 p. 177: Albrecht Ludwig Berblinger – Der Schneider von Ulm und der Flugpionier – The Tailer of Ulm

b) 200 Jahre Gleitflug: Schneiderlein im Sturzflug - (with picture above)

R.4.4.3 pp 178 – 179: Otto Lilienthal


c) Lilienthal’s Fatal Glider Crash in 1896: Evidence Regarding the Case of Death

Victor Hanson, Benny Bardrum, and Peter Illig
Aviation, Space, and Environmental Medicine - Vol. 79, No. 10, October 2008


R.4.4.4 pp 180 – 181: Wright brothers

b) Die Brüder Wright - http://de.wikipedia.org/wiki/Br%C3%BCder_Wright

Remark to p. 180: «Biplane gliding machine»: There is an error in the German version:  
The indicated distance of 622.5 m should be replaced by 622.5 ft = 189.7 m: (1 ft = 0.3048 m).  
[The corresponding distances in the English version a) are correct].

R.4.4.5 p. 182: Der Transatlantikflug von Lindbergh - Bilder aus: www.google.ch/

b) Transatlantic flight - http://en.wikipedia.org/wiki/Transatlantic_flight


(Lindbergh geriet in den USA wegen seiner Nazi-freundlichen und Juden-feindlichen Einstellung stark unter Beschuss, nicht zuletzt von Präsident Roosevelt. Erst viel später, im Jahre 1957, als er seine Autobiografie schrieb, entsetzte er sich über die NS-Konzentrationslager und die Vernichtung der Juden).

e) Planet Wissen Startseite – Navigationspfad – Luftfahrt
http://www.planet-wissen.de/wissen_interaktiv/html_versionen/luftfahrt/index.jsp

R.4.4.6 p. 183: Der Zeppelin – Die Katastrophe der «Hindenburg» (1937)

b) Last Photograph of Count Ferdinand Von Zeppelin, Inventor of the Zeppelin Airship
http://www.elposters.de/~ag/Last-Photograph-of-Count-Ferdinand-von-Zeppelin-Airship-Poste ...

d) Infos zum Thema «Zeppelin» - Die Luftschiffe von Ferdinand Graf von Zeppelin
http://www.zeppelinfan.de/html-seiten/deutsch/luftschiffe/zeppelin.htm

e) AKTUELLER ARTIKEL – Der Zeppelin flog wieder
http://www.wasistwas.de/aktuelles/artikel/link/435866c988/article/der-zeppelin-flog-wieder.html

R.4.4.7 p. 184: Sailplanes

R.4.4.8 p. 185: Jet aircraft
g) Rücksanstreiber – (Recoil drive) - http://re-flugzeugen-info/rueckstoessantrieb.php
h) Flugzeugtriebwirke – Basiswissen Schule Physik http://m.schuelerlexikon.de/mobile_physik/Flugzeugtriebwirke.htm
i) Rückstoss - http://de.wikipedia.org/wiki/%C3%BChucksrele%C3%9F

R.4.4.9 p. 186: Jet engine of a jet airliner
c) AIR-Breathing ENGINES - http://settlement.arc.nasa.gov/Nowicki/SPB1A6.HTM
d) Strahltriebwerk - http://de.arc.fo.de/Strahltriebwerk
(Zur klaren Darstellung wurde die Figur vom Autor retouchiert)

R.4.4.10 p. 187: Take-off of Boeing 747. 81
a) Lift Coefficient & Thin Airfoil Theory http://www.aerospaceweb.org/question/aerodynamics/q0136.shtml
c) John S. Denker: See How It Flies
(A new spin on the perceptions, procedures and principles of flight)
Published by McGraw – Hill Companies - Copyright @1996 – 2008 jad
Chapter 2: Section 2.4: «Angle of Attack Awareness and Angle of Attack Management»

R.4.11 p 188: Helicopters
Fotos von Hubschrauber: www.google.ch/search Helicopters
c) How helicopters fly and are controlled - http://www.re-airplane-world.com/how-helicopters-fly.html
e) Physikalische Grundlagen zum Hubschrauber - http://re-heil-fan.org/index.php/Physikalische_Grundlagen
f) Fotos von Hubschrauber: www.google.ch/search Helicopters

R.4.12 p. 189: About the Physics of Helicopters
c) How can a helicopter fly up the sky? Why does it need an upward tilt arm?
http://www.helip.org/lg/helicopter/helicopter_e.html
http://www.helip.org/lg/helicopter/helicopter_e.html
(e) Hubschrauber - www.grider.de/Aerodynamik%20der%20Hubschrauber%20dor
(contains pictures of forces acting on Helicopters and tail rotor; Figures adapted to English by P. Brüesch)
http://www.heliport.de/fotos/hubschrauber/physiklexikon/
Bird Tintenfisch auf Flug ins Winterquartier (i.e. Alpensegler Sprint 474; R.4.1.10, http://de.wikipedia.org/wiki/Tintenfische)

Appendix 4-A-1-1: Basic Equations of Aerodynamics
Chapter 2: Basic Aerodynamic Principles and Applications - PDF www ohio edu/people/ujdeha/chapter 2_basic-aerodnam pdf


Appendix 4-A-1-3 Derivation of Bernoulli Equation from Reference R.A.1.18; pp 471 – 474; R.A.1.10, R.A.1.11

4-A-1-4 Appendix 4-A-1-4: Vortex System of an Airplane: http://www.toeging/net/flieger/profil/aerodyn.html Bild des Wirbelsystems am Flugzeug - Figure adapted from German to English by P. Brüesch.


Appendix 4-A-2-1: Zur Herleitung der Reynolds Zahl (Derivation of Reynolds Number)
   a) Intuitive Derivation of Reynolds Number
      Die heuristische Herleitung beruht nicht auf Trägheits- und Reibungskräften, sondern auf Leistungen, d.h. auf der Aenderungsrate der kinetischen Energie und dem Leistungsverlust durch Reibung des Fluids
   b) Low Reynolds number flows - www.hitech-projects.com/.../Low%20Reynolds%20
   c) Hocine Oumeraci - Leichtweiss – Institut für Wasserbau; Technische Universität Braunschweig
      Vorlesungssbuch für das Grundfach »Hydrodynamik«
      Kapitel 11: Laminare und turbulente Strömung
      Abschnitt 11.5.2 , p. 202; Heuristische Herleitung der Reynolds Zahl auf der Basis der Trägheitskraft und der Reibungskraft eines sich durch ein Fluid (Wasser oder Luft) bewegenden Objektes
      http://www.tu-braunschweig.de/Medien.../skript-hydmechanik.pdf

Appendix 4-A-2-2: Gliding Octopuses (i.e. Calmaries and Common Octopuses (Kalmare))

R-A-2-3 Octopuses (i.e. Calmaries and Common Octopuses (Kalmare))
   c) Fliegende Meerestiere: Tintenfische übertreffen Sprint – Weltrekord www.spiegel.de/.../fliegende-meerestiere-tintenfische-uebertreffen-sprint
   d) Kalmare: http://de.wikipedia.org/wiki/Kalmare
   e) Kraken: http://de.wikipedia.org/wiki/Kraken
   f) PDF Tintenfisch: www.fischinfo.de/pdf/14TINTENFISCH.pdf
   g) Pictures from: www.gooqotl.ch - Images // Tintenfisch / Octopus

R-A.3.1 p. 4-A-3-1: The 5 Classes of Vertebrates
   b) Vertebrates: http://bio.edu.ee/animals/segro.htm

R.A.3.2 p. 4-A-3-2: Bird Migration
   b) Text: http://de.wikipedia.org/wiki/Vogelflug
   c) Image of Bord migration from - http://uwz.birdlife.ch/aktivitaten02.html

R.4.3.3 p. 4-A-3-3: Migrating Birds (Zugvögel) Stare auf Flug ins Winterquartier Sabina Galliati: Der Sonntag, Nr. 9, 3. März 2013

R.A.3.4 p. 4-A-3-4: Weltrekord im Dauerfliegen (08.10.2013) - World Record in long-distance flight
   c) Dr. Felix Liechti (Schweizerische Vogelwarte Sempach)
R-A-3-5  p. 4-A-3-5 - Coligo's (Riesngleiter)
   b) Riesengleiter (Colugo's) - http://de.wikipedia.org/wiki/Riesengleiter
   c) Riesgleiter (Pelzflatterer) - http://bedrue.frenzaige.de/riesengleiter2.htm
   d) Was haben Affen mit Riesengleitern zu tun?
      http://www.wissenschaft.de/wissenschaft/hintergrund/285029.html

R-A-3-6  p. 4-A-3-6 - Theological Reflections on Alfred Hitchcock's «The Birds»

R.A.4.1. p. 4-A-4-1: Airbreathing jet engines (schematic)
   a) See References a), b), c), d), e) of R.4.4.9, p. 186
   b) [DOC] Die historische Entwicklung von Flugzeugantrieben - http:// ancor.de/phnty/txt/Facharbeit.doc
      (Figuren - Texte von P. Brüesch neu geschrieben)