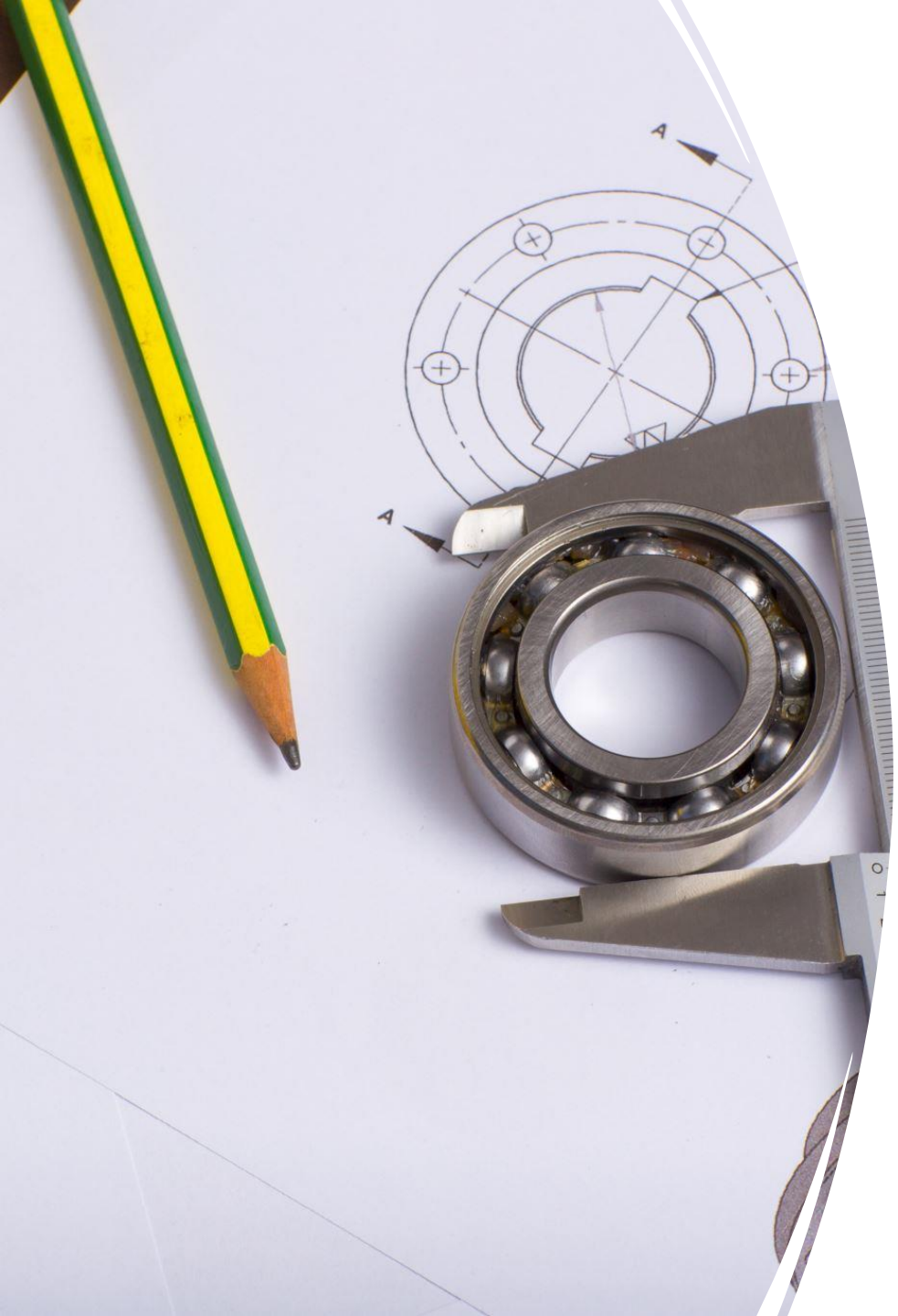
KINEMATICS FUNDAMENTALS

Terminology. Degrees of Freedom. The Grashof Condition and Formula.



Learning Outcomes

- Define the links of fourbar linkages: ground, crank, coupler, and rocker.
- Define Grashof Condition and its relation to the design a fourbar mechanism.

Kinematics Design of Mechanisms - Fourbar Linkages:

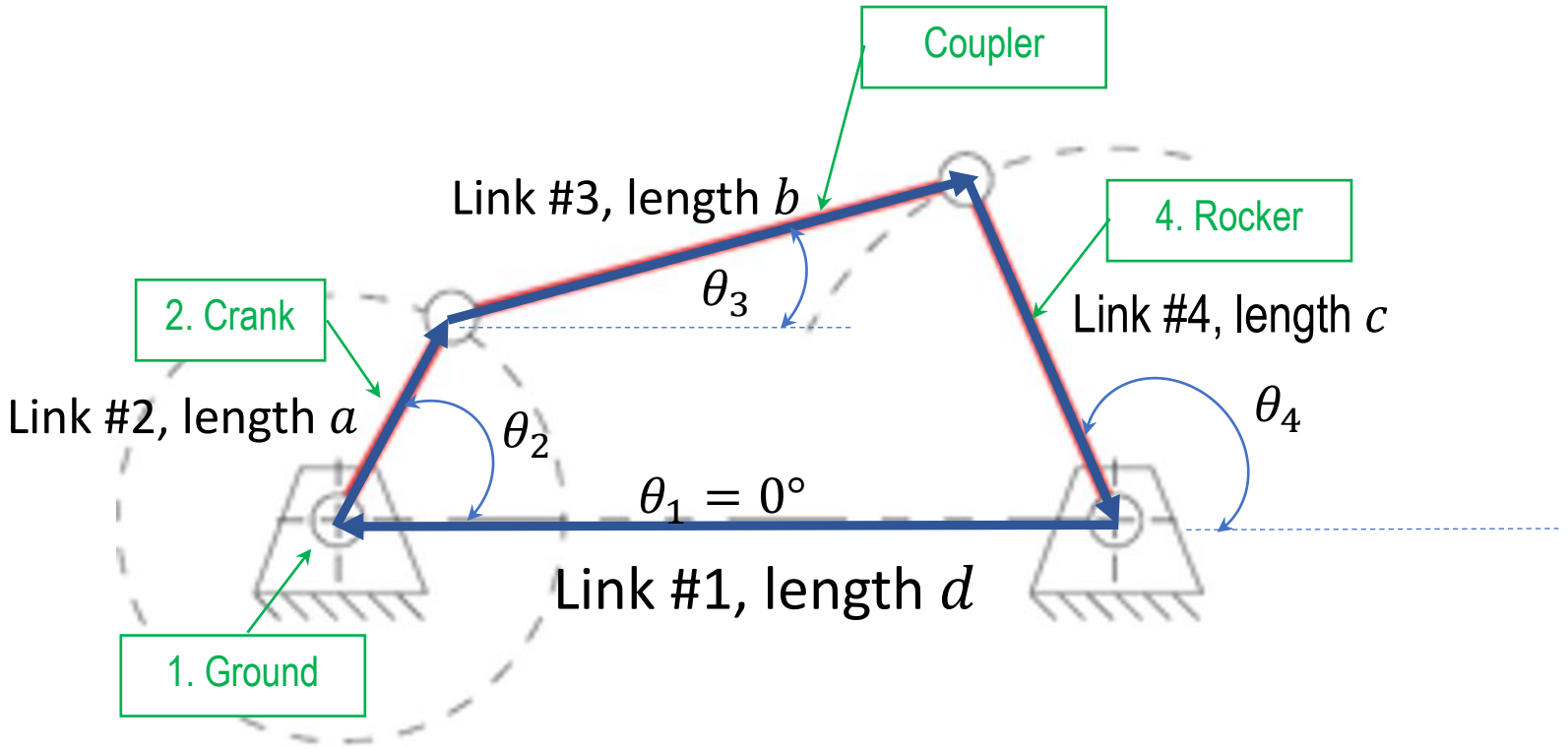
- The science of mechanism kinematics is roughly divided in two divergent topics:

    1. Analysis
    2. Synthesis

- Analysis: It is study of motions (kinematic) and forces (kinetic) concerning different parts of an *existing mechanism*.

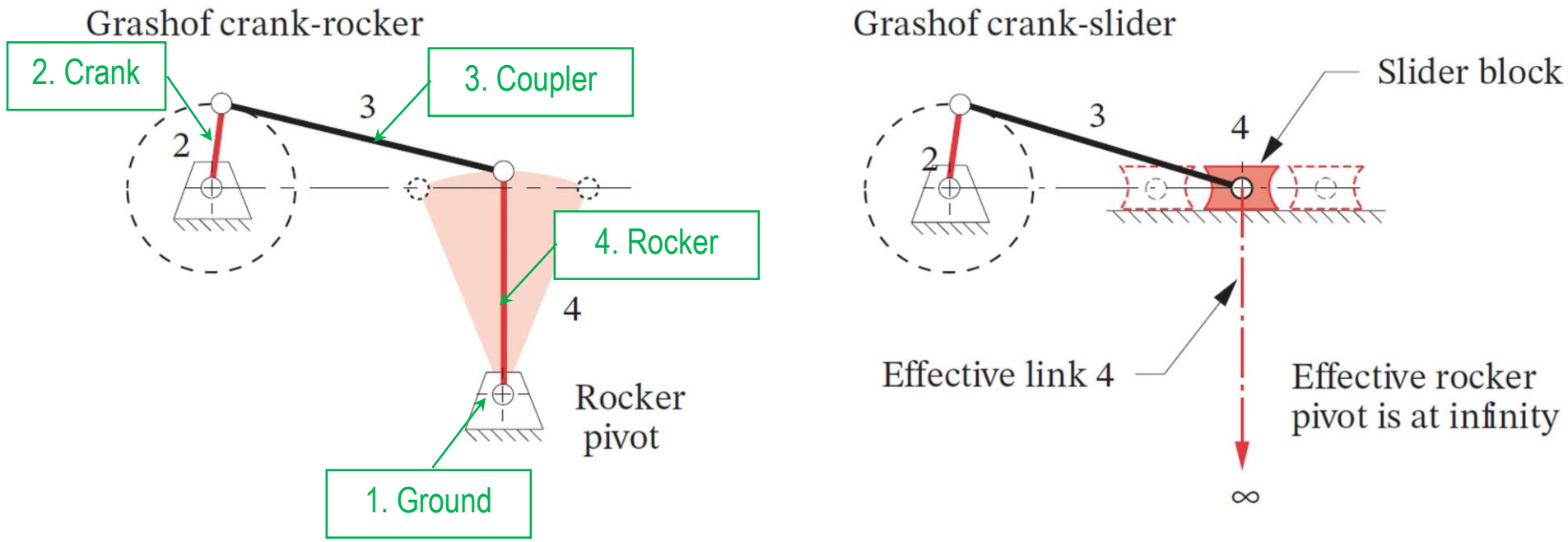
- Synthesis: It is study of the design of the mechanism and its different links.

Fourbar Linkages: Ground, Crank, Coupler, and Rocker.



- Length of the links are a-b-c-d.
- Angles are positive in RHR direction (or CCW).
- ***Note***: A link connected to ground by a hinged joint that can rotate 360° is usually called a crank.

Fourbar Linkages: Ground, Crank, Coupler, and Rocker.



(*a*) Transforming a fourbar crank-rocker to a crank-slider

Classification of the Fourbar Linkage

- The classification of planar four-bar linkages into three basic types depending on the use of *revolute or prismatic joints.* These are:
  - *RRRR linkage:* This type has four revolute joints, which allow the bars to rotate around fixed points.
    - The planar quadrilateral linkage is a general term for this type.
    - Examples of RRRR linkages are the double-crank, crank-rocker, double-rocker, parallelogram, antiparallelogram, deltoid, and trapezium linkages.

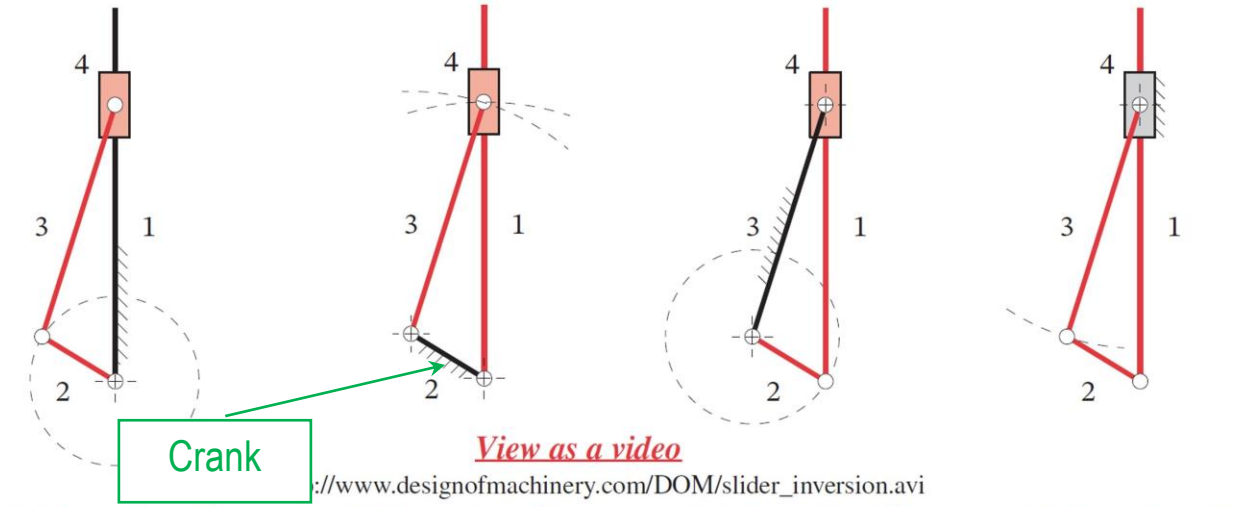
Classification of the Fourbar Linkage

- *RRRP linkage* (or PRRR or RPRR or RRPR): This type has three revolute joints and one prismatic joint, which allows one bar to slide along a line.
  - The slider-crank linkage is a common example of this type, where one bar is a crank, another bar is a slider, and the third bar is a connecting rod.
  - Other examples of RRRP linkages are the Whitworth quick return, crank and slotted lever quick return, and fixed piston mechanisms.

- *RRPP linkage:* This type has two revolute joints and two prismatic joints, which allow two bars to slide along perpendicular lines.
  - The Scotch yoke linkage is an example of this type, where one bar is a crank, another bar is a slider, and the third bar is a yoke that converts the rotary motion of the crank into the linear motion of the slider.

Fourbar Linkages: Ground, Crank, Coupler, and Rocker.

- The *slider-crank linkage* is constructed from four links connected by three revolute and one prismatic joint, or RRRP.
- It can be constructed with crank and a slider connected by the connecting rod.



Grashof Condition

- The *Grashof condition* is a criterion used in the design of planar (2D) four-bar linkages, which are common mechanisms in engineering.
- The Grashof condition helps to determine whether a four-bar linkage can achieve continuous rotation or oscillation. The condition is based on the lengths of the linkages in the mechanism.

Note: After the *synthesis or design of fourbar linkages*, the Grashof condition is always computed to determine whether the power source achieve a complete revolution.

Grashof Condition and Four-Bar Linkages:

- In summary, for a four-bar linkage to satisfy the Grashof condition, it must meet the following criteria:
  - It must have **four links** (as the name suggests).
  - The sum of the **shortest** and **longest** link lengths (denoted as **S** and **L**, respectively) must be less than or equal to the sum of the **remaining two** link lengths (denoted as **P** and **Q**).
  - Mathematically: $S + L \leq P + Q$.
  - When this condition holds, the linkage is Grashof, and at least one of the links can complete a full rotation.
  - If $S + L > P + Q$, the linkage is non-Grashof, and none of the links can rotate completely.

Grashof Condition and Four-Bar Linkages:

- So, four-bar mechanisms are classified by three major categories which are: *Grashof, Non-Grashof, and Special Case:*

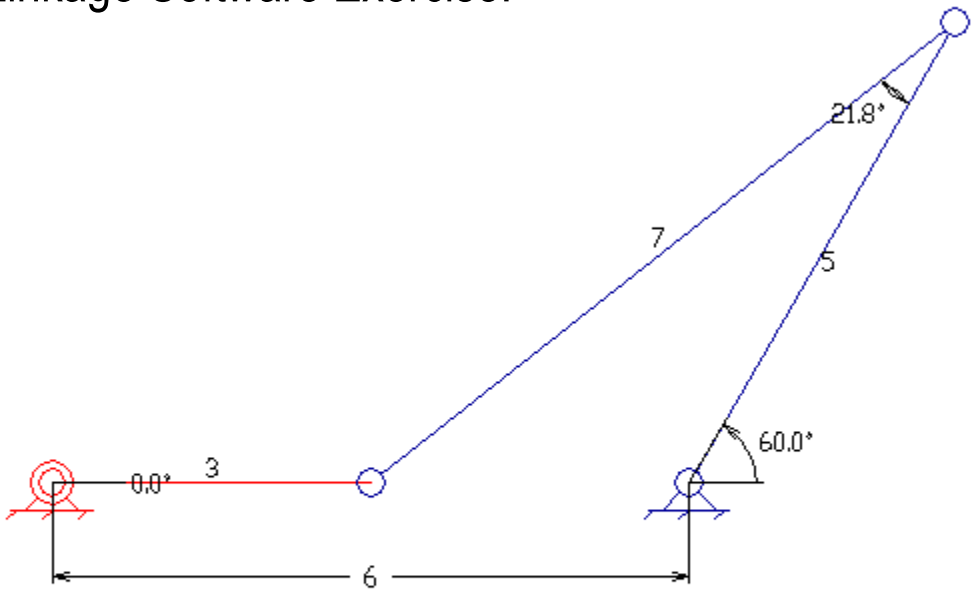
- Class I: if shortest link fully rotate with respect to a neighboring link: $S + L < P + Q$
- Class II: no link will be capable of a complete relative to any other link: $S + L = P + Q$
- Class III: indeterminate when : $S + L > P + Q$

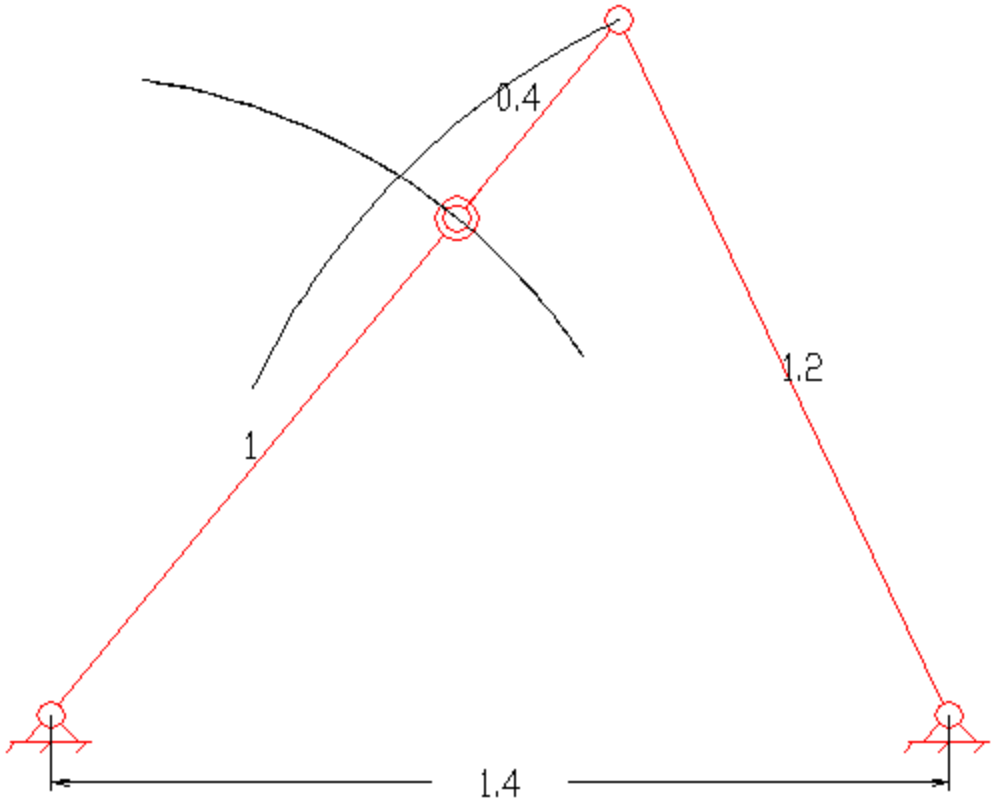
$$S + L \leq P + Q$$

Where:
S is the length of the shortest link
L is the length of the longest link
P is the length of a different link, and
Q is the length of the remaining link.

Kinematics Design of Mechanisms

- Linkage Software Exercise:





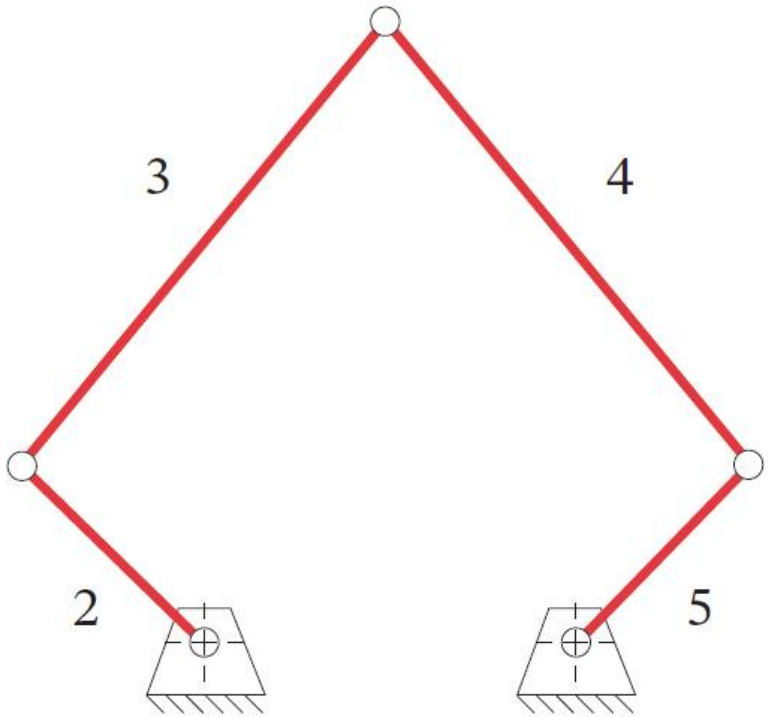
Source: https://en.wikipedia.org/wiki/File:Grashof_Type_I_Four-Bar_Kinematic_Inversions.gif

TABLE 2-4 Barker's Complete Classification of Planar Fourbar Mechanisms

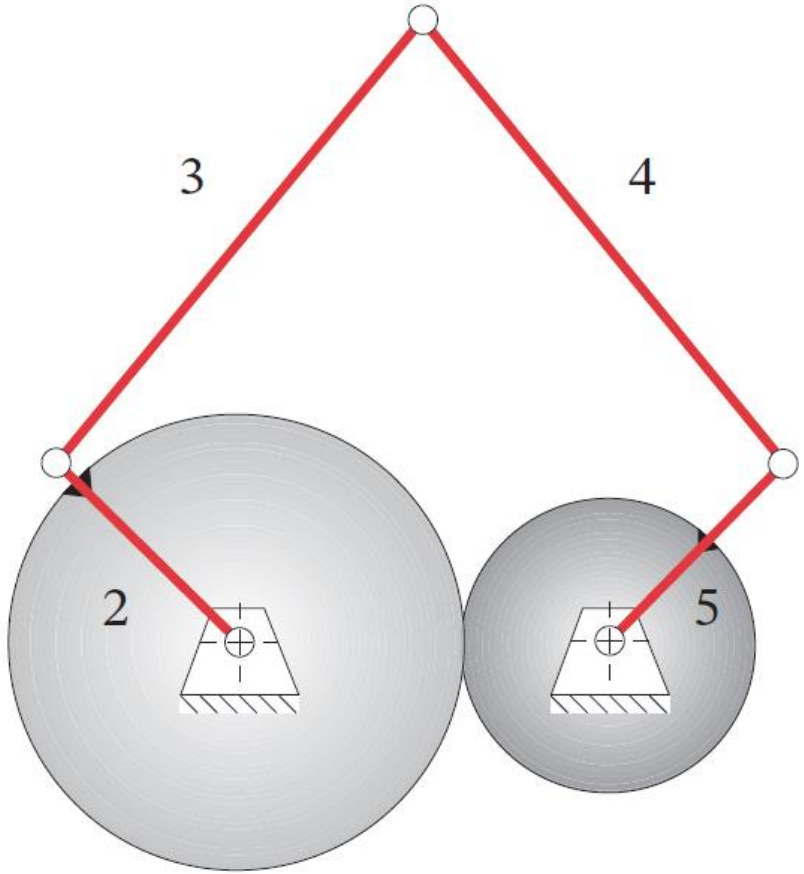
Adapted from ref. [10]. s = shortest link, l = longest link, Gxxx = Grashof, RRRx = non-Grashof, Sxx = Special case

Type	$s + l$ vs. $p + q$	Inversion	Class	Barker's Designation	Code	Also Known As
1	<	$L_1 = s$ = ground	I-1	Grashof crank-crank-crank	GCCC	Double-crank
2	<	$L_2 = s$ = input	I-2	Grashof crank-rocker-rocker	GCRR	Crank-rocker
3	<	$L_3 = s$ = coupler	I-3	Grashof rocker-crank-rocker	GRCR	Double-rocker
4	<	$L_4 = s$ = output	I-4	Grashof rocker-rocker-crank	GRRC	Rocker-crank
5	>	$L_1 = l$ = ground	II-1	Class 1 rocker-rocker-rocker	RRR1	Triple-rocker
6	>	$L_2 = l$ = input	II-2	Class 2 rocker-rocker-rocker	RRR2	Triple-rocker
7	>	$L_3 = l$ = coupler	II-3	Class 3 rocker-rocker-rocker	RRR3	Triple-rocker
8	>	$L_4 = l$ = output	II-4	Class 4 rocker-rocker-rocker	RRR4	Triple-rocker
9	=	$L_1 = s$ = ground	III-1	Change-point crank-crank-crank	SCCC	SC* double-crank
10	=	$L_2 = s$ = input	III-2	Change-point crank-rocker-rocker	SCRR	SC crank-rocker
11	=	$L_3 = s$ = coupler	III-3	Change-point rocker-crank-rocker	SRCR	SC double-rocker
12	=	$L_4 = s$ = output	III-4	Change-point rocker-rocker-crank	SRRC	SC rocker-crank
13	=	Two equal pairs	III-5	Double change point	S2X	Parallelogram or deltoid
14	=	$L_1 = L_2 = L_3 = L_4$	III-6	Triple change point	S3X	Square

* SC = special case



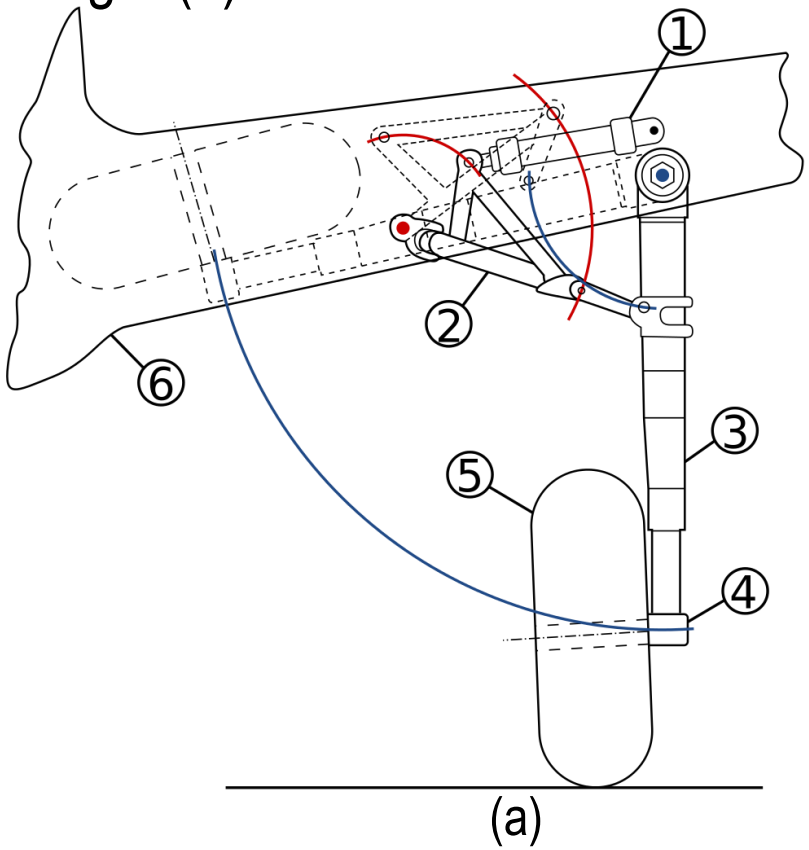
(*a*) Fivebar linkage—2 *DOF*



(*b*) Geared fivebar linkage—1 *DOF*

Kinematics Design of Mechanisms

- Match the part, joints and links, in (a) to the picture in the right (b):



(a)

(b)

Figure 1–3 Landing Gear of an Aircraft Comparison.