Chapter 6

Operation Characteristics of Turbine and Compressor Blades

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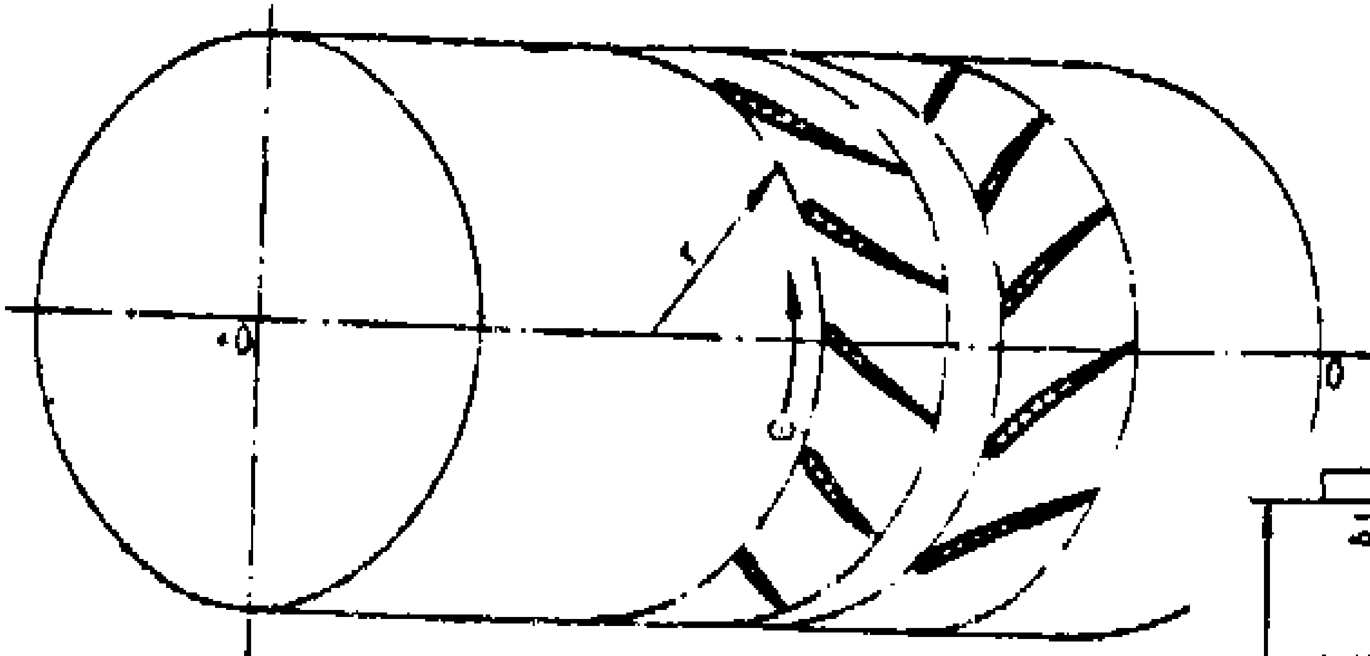
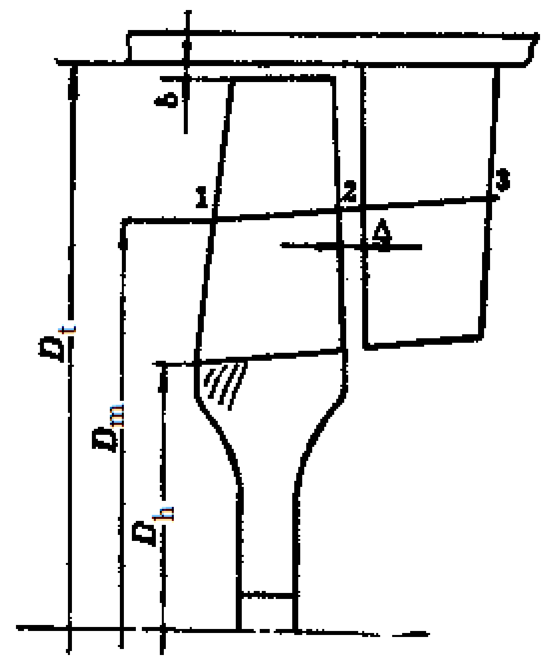
1. Axial Compressor Blades



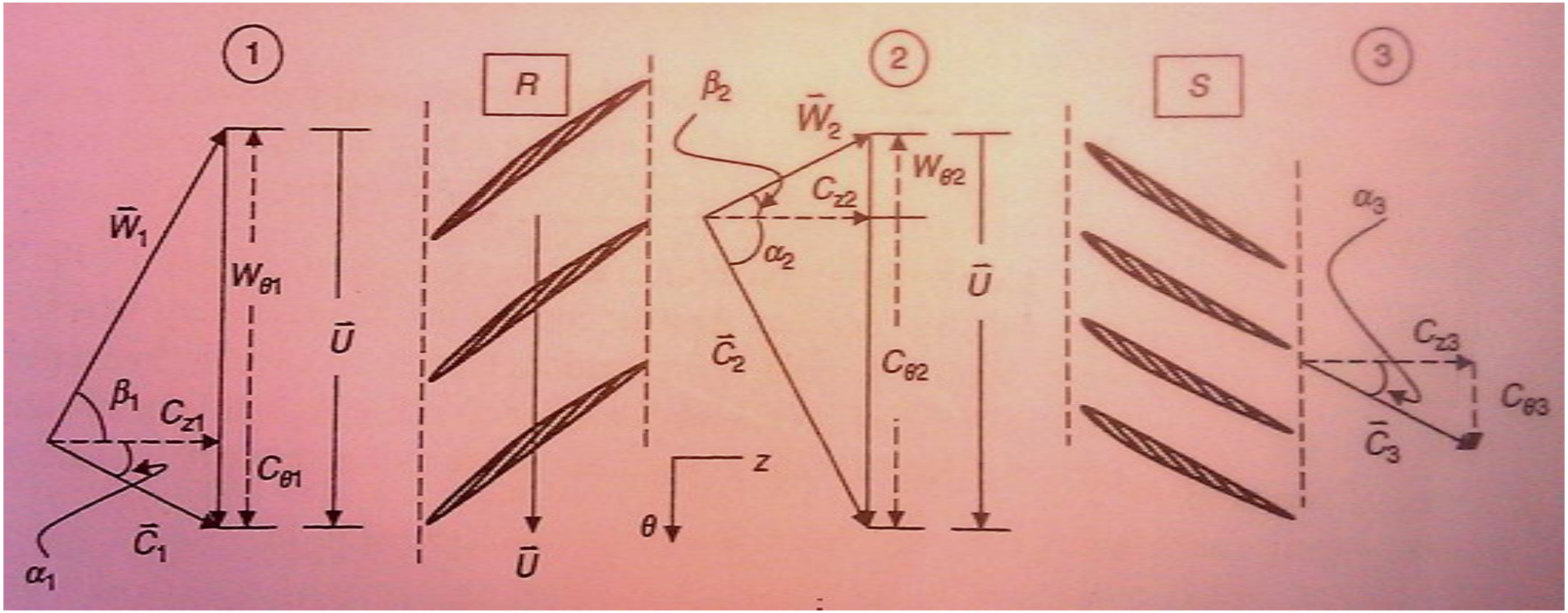


There are two velocities to be considered- the air flow velocity and the rotational velocity of the compressor.

1. Axial Compressor Blades

Definition of Flow Angles

The flow angles are measured with respect to the axial direction, or axis of the machine, and are labeled as α and β, which correspond to the absolute and relative flow velocity vectors C and W, respectively.

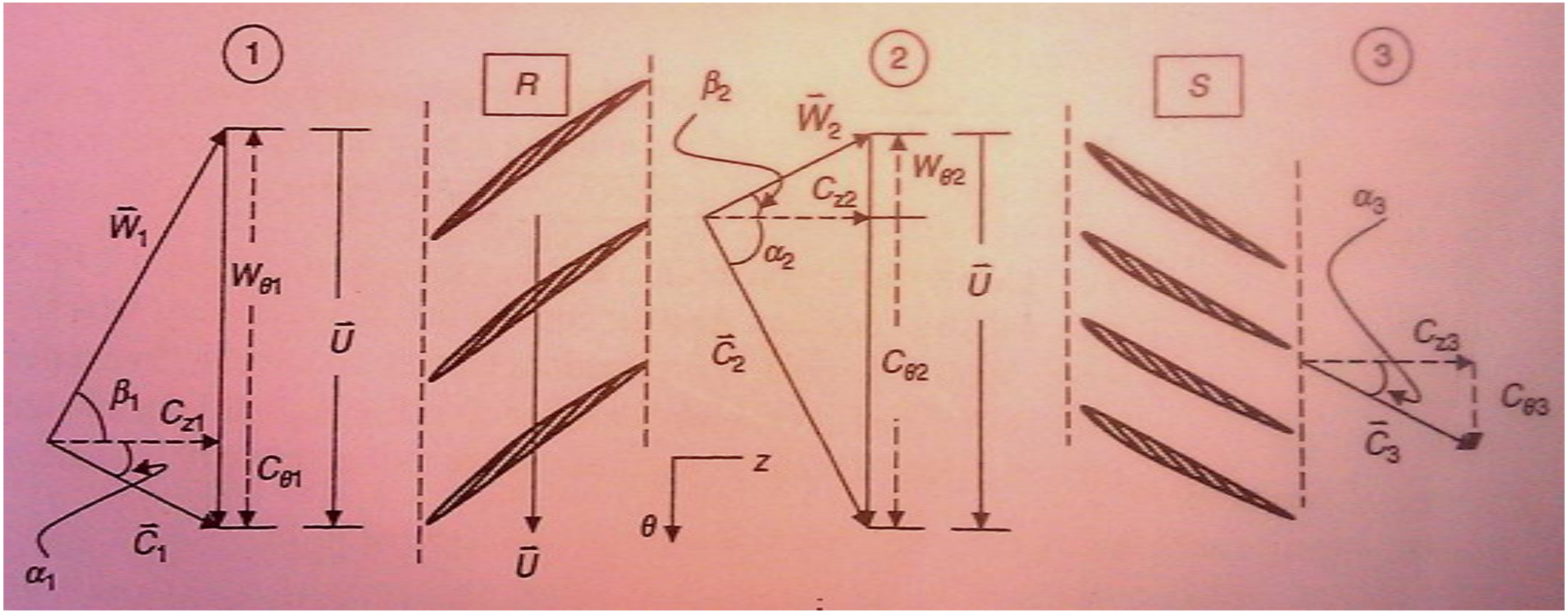


$$\vec{C} = \vec{W} + \vec{U} \qquad \vec{U} = \omega r \hat{e}_\theta \qquad \vec{C}_1 = \vec{C}_3$$

1. Axial Compressor Blades

Definition of Flow Angles

The boundary layers on the blades of compressor and fans, as well as their hub and casing, are exposed to an adverse, or rising pressure gradient. Boundary layers exposed to an adverse pressure gradient, due to their inherently low momentum, cannot tolerate significant pressure rise.

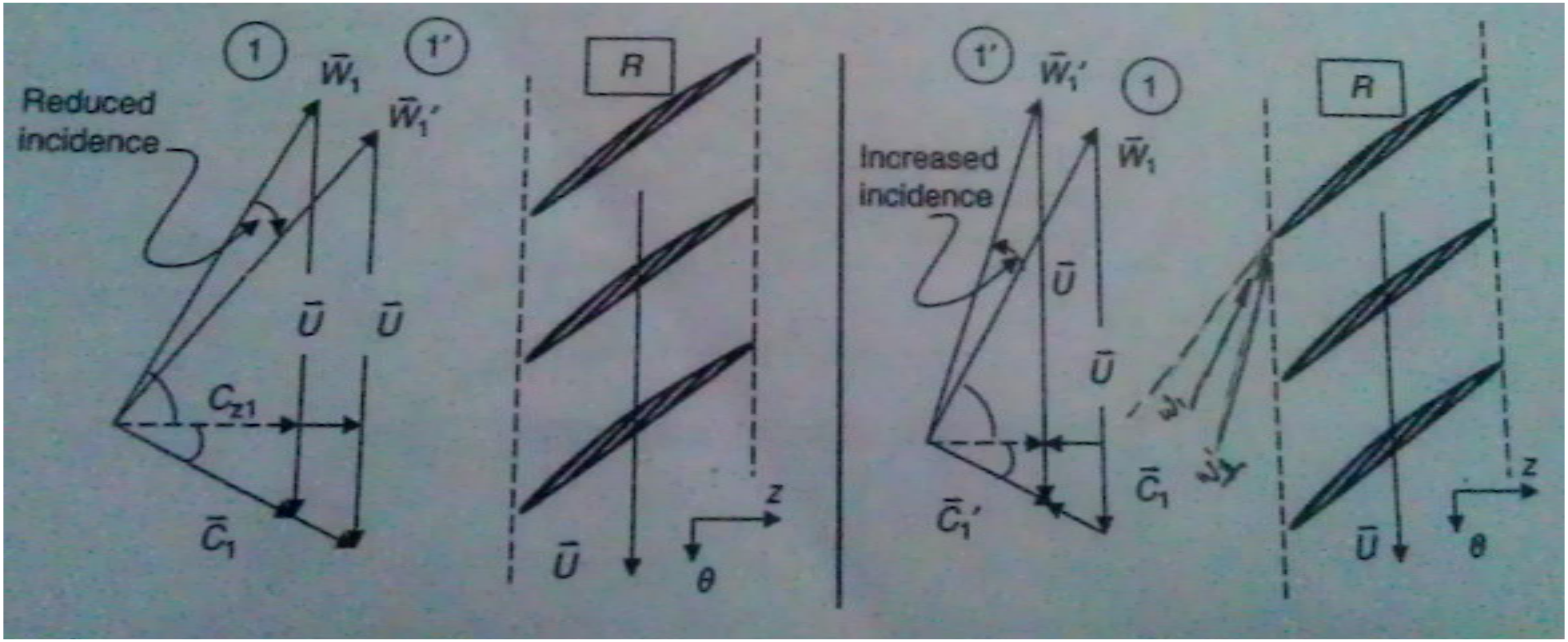


Consequently, to achieve a large pressure rise, axial-flow compressors and fans need to be staged.

1. Axial Compressor Blades

Flow Rate Effects

The effect of increased mass flow rate while maintaining the same rotational speed is to reduce the blade incidence angle.

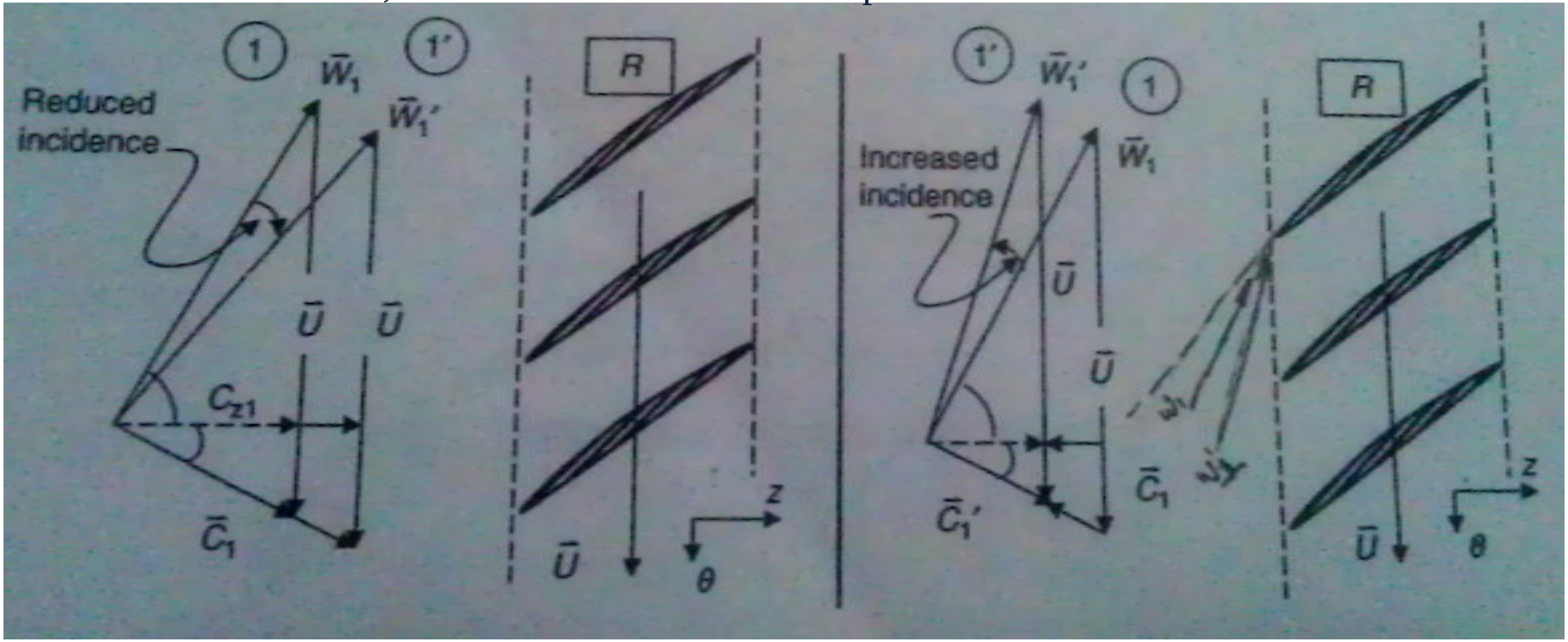


The effect of decreased mass flow rate, with constant rotational velocity is to expose the blades to a higher incidence angle.

1. Axial Compressor Blades

Flow Rate Effects

The reduced flow rate leads to an increased compressor temperature (or pressure ratio). However, there is a limitation on how low the flow rate, or axial Mach number, can sink before the blades stall, for a fixed shaft rotational speed.



The increased mass flow rate leads to a reduction of the stage total temperature, which has its own limitation. The phenomena of negative stall could be entered as the inlet Mach number is reduced significantly.

1. Axial Compressor Blades

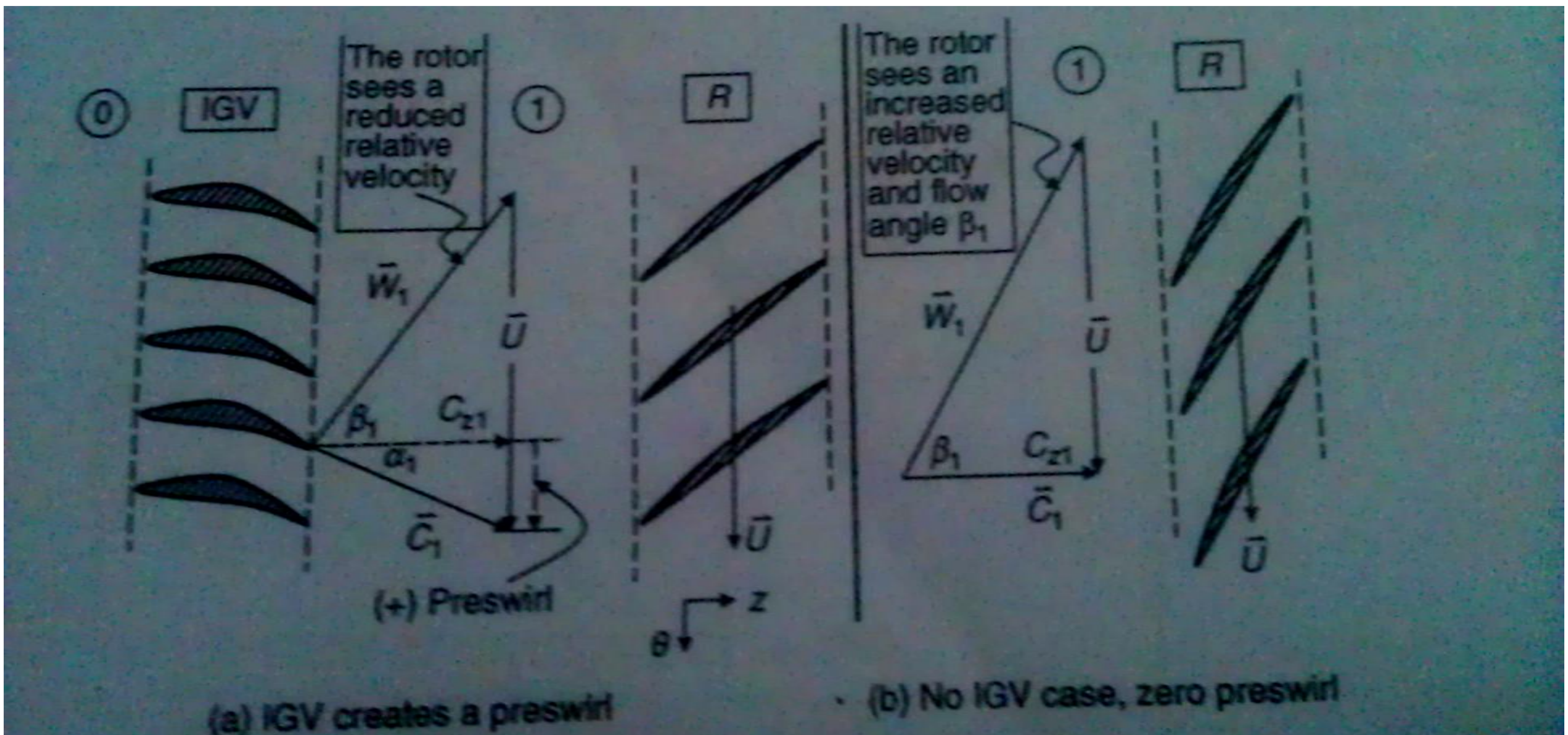
Inlet Guide Vanes

- The flow field entering an IGV is swirl-free and thus the function of the IGV is to impart positive swirl to the incoming fluid. This in effect reduced the rotor blade loading whose purpose is to impart angular momentum to the incoming fluid.
- The blade passage in the IGV form a subsonic nozzle (i.e. contracting area) and cause flow acceleration across the blade row.
- The result of the flow acceleration is found in static pressure drop due to flow acceleration, as well as a total pressure drop due to frictional losses of the blade passage.
- Hence, if the compressor design could avoid the use of an IGV, then certain advantages, including cost and weight savings, are gained .
- The advantage of operating at higher tip speeds at times overweighs the disadvantages of an IGV.

1. Axial Compressor Blades

Inlet Guide Vanes

The inlet swirl angle may be zero or be adjustable in the range of 30 above or below zero, or more, using a variable geometry IGV to relieve the relative tip Mach number, improved efficiency at compressor off-design operation, and provide for rapid thrust/lift modulation in military aircraft.



2. Compressor Instability- Stall and Surge

Compressor Stall

- The phenomena of stall in a compressor can be understood as flow separation from the suction or pressure surfaces of an airfoil with large positive and negative angles of attack, respectively.
- The stalled flow in a compressor rotor may be initiated with a single blade at a certain radius. The stalled blade passage acts as a blocker and diverts the flow to the neighboring (yet uninstalled) blades.
- Following that, the flow diversion from the stalled passage to the one above the stalled blade causes an increase in that blades incidence angle, pushing it towards stall.
- Then the diversion to the subsequent upper blades, in a rotation.
- The stalled flow in a passage is moving in the opposite direction to the blade rotation, hence it is given the name **rotating stall-** with an angular speed half of that of the rotor angular speed.
- The recovery from the stalled operation in a compressor exhibits a hysteresis behavior, which accompanies systems governed by non-linear dynamics.

2. Compressor Instability- Stall and Surge

Compressor Surge

- The coupling between the compressor stall instability and the combustion chamber resonant characteristics could lead to an overall breakdown of the flow, or flow oscillation, in compressor and combustor.
- The overall flow breakdown in the system composed of compressor and combustor is called *surge*.