INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING

ISSN (ONLINE): 2321-3051

Vol.2 Issue.12,

December 2014.

Pgs: 1-10

A Review on Efficiency of Inlet with Varying Ramp Angle

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Abstract

An air inlet can protrude from the aircraft surface or be submerged into the aircraft body. A submerged inlet has in general lower aerodynamic drag than an inlet that protrudes from the surface of an aircraft and is therefore the most preferred design option to the flight industry. An air inlet should ideally not decrease the total pressure of the air which enters and at the same time only give rise to a minimum amount of additional aerodynamic drag. Although angle variation in the air inlet have several affects other than inlet efficiency also the air breathing system of the airplanes. As the varying ramp angle in the airplane, air jet etc, may create the problems on the working of the air inlet. So this review on efficiency of inlet with varying ramp angle is very much needful for the system as well as for the designers, and also it would be very helpful for the future perspective for researches.

***Keywords**:* Ramp Angle, Air Intake, Pressure Distortion.

1. Introduction

The efficiency of air inlet may vary due to the change in angle. When studying air flow over a solid body it is appropriate to divide the analysis of the flow into two parts. Close to the surface of the solid body friction forces play an important part whereas further out into the free stream friction forces can be neglected. The idea is to treat the air flow close to a surface separately. This concept was first suggested in 1904 by a man named Ludwig Prandtl. Due to the friction between the surface and the moving gas, the air flow closest to the surface will tend to adhere. This phenomenon is known as the no-slip condition.

In this paper we would review about the inlets in the airplanes. All types of inlets such as scoop inlet and flush inlet would be reviewed in this thesis. Advantages and disadvantages exist with both design choices. While the scoop inlet has the advantage of avoiding the low energy boundary layer which reduces the efficiency of an air inlet, it has typically the disadvantage of a greater increase of aerodynamic drag compared to a submerged inlet. These criteria cannot be fully met by any air inlet, but design parameters can be changed to come close to an optimum for a specific flight condition. For low drag it is advantageous to use a flushed inlet which is submerged into the surface of the body into which it is placed. The flush type is also advantageous to avoid foreign object damage on the inlet. We would focus on the ramp walls such as Parallel walls, divergent walls and convergent walls. Through this we can evaluate the exact ramp efficiency would be measured as well.

2. Air Inlet – Air Intake System

The air intake is that part of an aircraft structure by means of which the aircraft engine is supplied with air taken from the outside atmosphere. The air flow enters the intake and is required to reach the engine face with optimum levels of total pressure and flow uniformity. These properties are vital to the performance and stability of engine operation. Depending on the type of installation, this stream of air may pass over the aircraft body before entering the intake properly. Figure 1 shows the flow chart of typical air intake system.

2.1 Needs of Air Inlet or Intake System

- A widely used method to increase the thrust generated by the aircraft engine is to increase the air flow rate in the air intake by using auxiliary air intake systems.
- The air flow enters the intake and is required to reach the engine face with optimum levels of total pressure and flow uniformity hence need of an air intake system.
- Deceleration of airflow at high flight mach numbers or aerodynamic compression with help of air intake.

2.2 Air Intake Design Requirement

The airflow first passes through the air intake when approaching the engine, therefore the intake must be designed to meet certain requirements of aircraft engines such as:

- The air intake requires enormous effort properly to control airflow to the engine.
- The intake must be designed to provide the appropriate amount of airflow required by the engine.
- Furthermore this flow when leaving the intake section to enter the compressor should be uniform stable and of high quality.
- Good air intake design is therefore a prerequisite if installed engine performance is to come close to performance figures obtained at the static test bench.
- The engine intake must be a low drag, light weight construction that is carefully and exactly manufactured.
- These above conditions must be met not only during all phases of flight but also on the ground with the aircraft at rest and the engine demand maximum, thrust prior to take off

3. Literature Review

Many studies have been conducted in both the stationary and relative frames of measurement to investigate how fluid flow through a fan or compressor varies due to circumferential inlet total pressure distortions. The literature review resulted in five general publication categories with application to distortion and wake response. The first group of papers concerns inlet flow condition and blade lift response to distortion. The second group of papers concerns blade response to a transient blade incidence angle above the steady-state stalling angle. The third category concerns wake analysis with respect to variations in incidence angle or operating point on the map. The fourth category discusses the phenomena of the suction side total pressure profile appearing as a jet, or pressure excess, in the stationary frame of reference. The fifth category is limited to one paper discussing the effect of inlet total pressure distortion on inlet flow conditions and three dimensional wake responses.

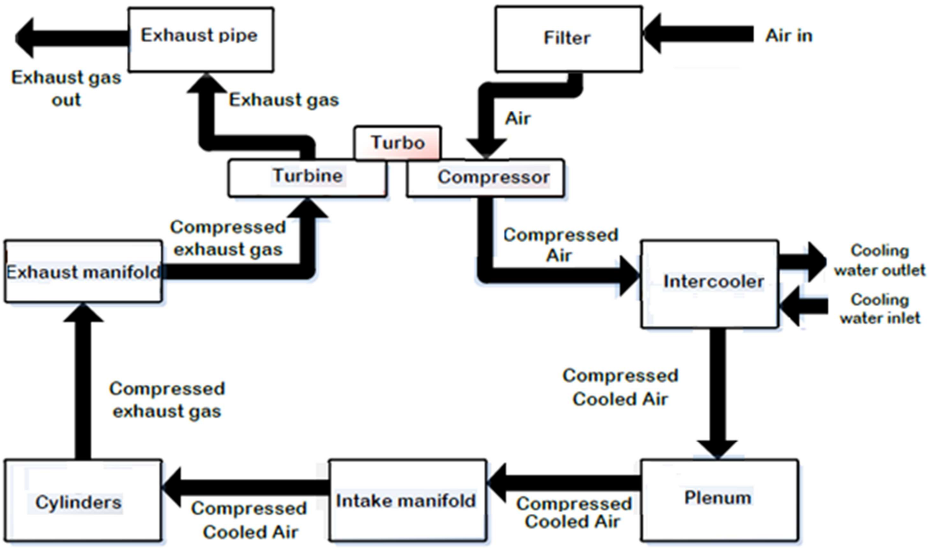

Figure 1: Flow Chart of Intake System

Several hundred documents exist in the literature which describes testing and research performed in an effort to improve compressor response to inlet total pressure distortion. Due to this extreme number of relevant publications, this literature review will emphasize steady-state circumferential pressure distortion in axial-flow fans and compressors.

Kacker and Whitelaw (1971) investigated the turbulence characteristics of two-dimensional wallets. They used static pressure distribution, mean velocity profiles, and wall shear stress to describe the mean properties of air jets. They used turbulence intensity, turbulent shear stress, and a turbulent energy balance to describe air jet properties. They concluded that detailed measurements were required to demonstrate the complexity of wall jet flows and confirmed that a satisfactory prediction of the mean and fluctuating properties was a formidable task.

Walker (1977) reviewed the theoretical relationships of isothermal ventilating air jets. Proper selection of inlet size and design, direction of air movement, air jet throw, entrainment, and spread of ventilation jets were required to predict system performance and to design an effective ventilation system. The review of theory included a free jet issuing from a circular hole and a free jet issuing from an infinitely long slot. He concluded that air jet theory could be used to describe velocity decay, entrainment, and air jet spread for many types of inlets and ventilation configurations.

Boon (1978) tested airflow patterns for various inlet arrangements and ventilation configurations. In most commercial livestock buildings, airspeed at animal level is greatly affected by the rate of ventilation. Temperature, relative humidity, airspeed, ventilation rate, and air movement were measured. Two stable airflow patterns were observed. Temperature variations from floor to ceiling relied on the direction of air movement.

Leonard and McQuitty (1987) investigated design criteria of ventilation inlets for animal housing. They concluded that a minimum Jet Momentum Number of 7.5 × 10–4 was required for developing a stable airflow pattern in isothermal situations. Ogilvie et al. (1990) investigated the effects of air inlets and floor layout on animal-level airspeed. They studied the relationship between jet momentum and airflow pattern near the floor. They found that the location and type of air inlets and the pen layout were two important components of a space ventilation system. They found that Jet Momentum Number (J) and the airflow to floor area ratio (Q/A), both indices of energy input into a room, correlated well with floor airspeed.

Jin and Ogilvie (1992) investigated airflow direction and airspeed at animal level. They showed velocities in the floor region correlated well with inlet configuration, which included inlet type, dimension, and location of the inlet, incoming velocity, direction, and airflow rate.

4. Pressure Distortion Simulation Techniques

Studying about the air flow was first been suggested by Ludwig Prandtl (1904). Inlet flow distortions in fluid machinery are defined as variations of flow properties as a function of space and time and have been of major concern to turbo machinery designers for decades. These deviations from a steady uniform distribution of the flow properties can include variations in swirl, vorticity, turbulence, total and static pressures, velocity, temperature, flow angle, and fluid density. Circumferential distortions are viewed as being more critical than radial distortions due to the production of a disturbance normal to the airfoil motion, and resulting effects on angle of attack and stall margin. Figure 2 shows the inlet total pressure distortions and its configuration.

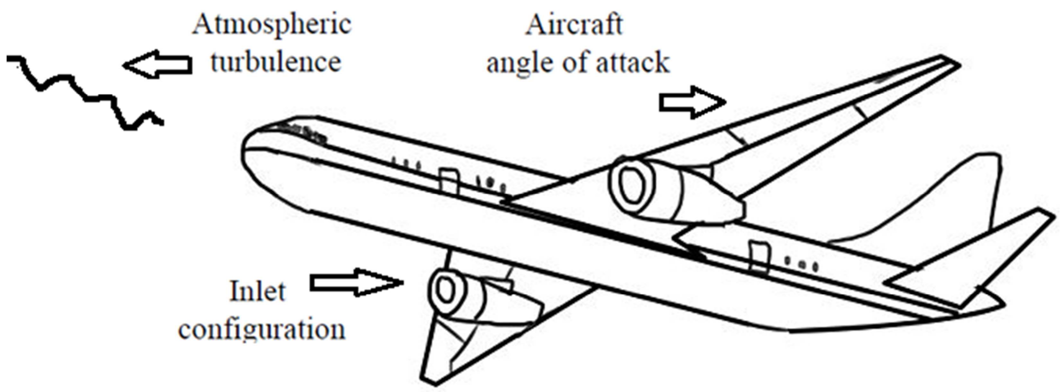

Figure 2: Inlet Total Pressure Distortions and its Configuration

Screens are typically used to impose steady-state total pressure distortions on inlet fans and compressors based on the simplicity of application and cost-effectiveness. The effect of fluid viscosity on the flow is to produce a viscous static pressure drop across the screen grid, as well as a deflection of streamlines to the screen outer edges. It is important to note that a distortion screen installed in front of a rotor will not produce an identical circumferential pressure defect pattern downstream at the aerodynamic interface plane of the rotor inlet due to upstream fluid communication between the screen and rotor. Although ideally the screens would produce “square-wave” pressure patterns at the inlet of the rotor, in reality there are transition regions at the edges of the screen. Therefore, total pressure at the rotor inlet as viewed in the relative frame will never be a “step function” but rather a continuous variation as the blade passes downstream of the screen. Figure 3 indicates the pressure distortion patterns.

5. Distortion and Wake Testing in Axial Flow and Compressors

A number of fan and compressor studies have been performed with regard to variations in inlet flow conditions due to distortion. Soeder and Bobula (47) investigated the effect of steady circumferential total pressure distortion on flow characteristics entering an aircraft engine using classical screens. They found that for a transonic turbofan engine, maximum and minimum flow yaw angles in the absolute frame occurred within the constant intensity distortion sector of the flow field as opposed to at the screen edges. They also found the yaw angle is usually the largest in the hub region for the screen configurations they tested. This yaw angle variation increased in magnitude as the flow approached the engine inlet. Increasing the screen blockage increased the yaw angle variation. They also discovered that the inlet pitch angle variation in the plane of the distortion is much smaller than the yaw angle variation, as would be expected for purely circumferential distortions.

Cousins (7) analyzed the unsteady blade surface pressures due to circumferential inlet total pressure distortion in a low-speed axial-flow compressor rig using on-rotor pressure transducers and a telemetry system. Stationary high-response probes were employed to capture wake pressure variations during rotating stall. He showed that it was feasible to develop a transfer function describing the dynamic blade response using data from on-rotor pressure measurements and Fourier transform techniques.

Gauden (18) investigated the performance and stalling behavior of a low-speed axial-flow compressor subjected to three different circumferential inlet distortion levels. He used steady-state instrumentation in the stationary frame of reference and high response pressure transducers mounted on the blades. He discovered that distortion screens reduced the mass flow rate through the compressor due to their low porosity and precipitated stall at a more open throttle valve setting than for undistorted operation.

Gauden found that with respect to the direction of rotor motion, a sharp increase in axial velocity was observed as the distorted segment was approached, implying a decreased angle of attack at the blade leading edge. This was due to flow blockage created by the distortion screens. As the blades passed circumferentially through the distorted flow region behind the screens, the axial velocity was reduced until the angle of attack was maximized, and then returned to its undistorted value at the trailing edge of the screen. The shape of the circumferential velocity profile remained roughly the same as the flow rate was decreased using a throttle valve.

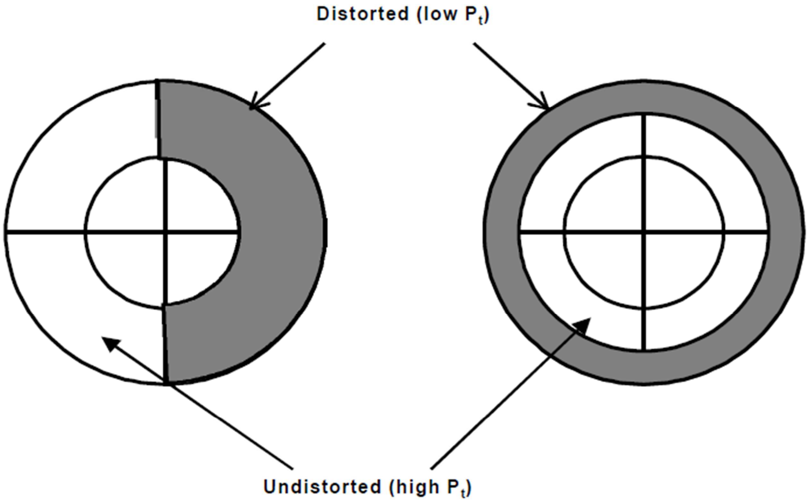

Figure 3: Pressure distortion patterns

Dancy (8) tested the performance and stalling behavior of a low-speed axial-flow compressor with circumferential inlet flow distortion. Similar to the results of Gauden for the same test rig, he discovered that axial velocity increased nearly 10 % as the leading edge of the screen was approached, then fell off sharply and leveled out. An opposite effect occurred at the "departure" end of the screen with respect to rotor rotation. He found that velocities in the undistorted segments of a partially-distorted inlet were higher than the constant flow velocity for a clean inlet. Although the compressor was set to produce the same volumetric flow rate in both cases, the flow rate increase in the undistorted region was insufficient to return the compressor to its original, undistorted volumetric flow rate. As a result, the undistorted compressor always had a higher flow rate. As the back pressure was increased, the flow rates for the distorted and undistorted compressors approached the same value due to a decreased axial velocity and, subsequently, a decreased total pressure drop across the screen. He also found rotating stall for RAF-6 airfoils to originate at the hub of the blade.

The second literature category, blade response to an unsteady incidence that exceeds the steady-state stalling angle, is presented next. Sexton (43) investigated the dynamic stalling characteristics of low-speed axial-flow compressor blades using blade mounted transducers and a multi-channel radio telemetry system. High incidence angles and stalling were induced using a distortion screen mounted in front of the IGV. This screen had a mesh of sufficiently low porosity as to insure incidence angles greater than the steady-state stalling angle. This allowed separation of the blade boundary layer behind the distorted region and reattachment in the undistorted region during each revolution. Sexton then developed a transfer function between the quasi-steady total pressure loss forcing function and the dynamic pressure loss response function. This transfer function in turn described the dynamic response of the rotor blade row flow and made possible the prediction of response to a given inlet distortion for a rotating stall model.

Neal (37) used a multi-channel FM telemetry system in conjunction with miniature blade-mounted transducers to investigate low-speed rotor blade lift response due to circumferential inlet flow distortions. He found that normalized lift for an undistorted compressor decreases as the volumetric flow rate is decreased and angle of attack is correspondingly increased. He explained this unusual behavior by noting that although the coefficient of lift increases with an increase in angle of attack, the decrease in volumetric flow rate causes a decrease in absolute lift. The normalized lift of the distorted compressor first increased and then decreased as flow rate was decreased. He explained this as being due to competing effects of changes in angle of attack, changes in volumetric flow rate, and changes in the level of distortion as the back pressure was increased by closing a downstream discharge valve. He presented an analysis of rotor blade lift and rotor inlet dynamic pressure for a rotor cycle during which the blade experienced a far greater incidence than the steady-state stalling angle.

Neal found that although the blade did eventually stall as it passed well into a distortion; the delay in the inception of stall was significant, with partial stalling of the instrumented rotor blade just prior to the blade's exit from the distorted segment. This corresponded closely to the highest angle of attack on the rotor blade during the rotor cycle. The dynamic stall event was typically characterized by a lift overshoot, which then collapsed and returned to the undistorted lift value after the trailing edge of the screen. This indicated boundary layer reattachment. The phenomenon of a blade experiencing an incidence angle beyond the steady-state stalling angle without stalling was also observed by Melick (35) and Henderson and Horlock (21), and was postulated to be a function of the rotor blade lift response.

Lakshminarayana, et al. (33) studied the effects of rotation and blade incidence on the properties of a low-speed fan rotor wake. They defined a wake semi-width at half the depth on both the pressure and suction sides of the wake and non-dimensionalized them by the rotor blade spacing in the circumferential direction. They found that the wake defect was reduced as rotor rotational speed increased and that the axial velocity wake defect was highest at the hub. Higher rotor speed gave lower axial velocity defect, and higher loading increased the axial velocity defect (or decreased the downstream decay rate of the axial velocity defect). The wake semi-width at a fixed loading did not change with an increase in rotor rotational speed. In addition, they found that wake semi-width was lower at lower loading and the growth was less rapid.

Shreeve and Neuhoff (45) found the wake of a small, transonic single-stage axial compressor to broaden at reduced throttle settings and increased blade speed. Henderson and Shen (20) investigated the influence of unsteady rotor response on a distorted flow field in a low speed axial flow rotor. They found that as the rotor was loaded by decreasing the flow coefficient, the boundary layer thickness, wake defect magnitude, and wake width all increased.

Reynolds, et al. (41) found the wake of an isolated low-speed rotor to be three dimensional in nature with an appreciable radial velocity due to an imbalance in the radial pressure gradient and centrifugal forces. They defined wake semi-widths on the rotor pressure and suction surfaces to obtain a width parameter which was non-dimensionalized by blade spacing.

Ravindranath and Lakshminarayana (39) performed an experimental study of the three-dimensional characteristics of the mean relative frame velocity in the wake of a moderately loaded compressor rotor blade. They defined a non-dimensional semi-width parameter as the sum of the characteristic widths on the pressure and suction surfaces normalized by the semi-blade spacing. They found the effect of blade loading was to sustain the wake asymmetry to a much larger extent downstream of the blade trailing edge. Increased loading also increased the velocity defect magnitude, slowed the decay rate, and induced higher radial velocities. They found the wake width to vary considerably in the radial direction. The width increased towards the hub- and annulus-walls, which was attributed to the complex interaction of the wake, hub-, or annulus-wall boundary layers, and secondary flows (tip vortex in the case of the annulus-wall). They found the static pressure to vary across the wake as well as in the wake near the blade trailing edge due to inviscid effects, which is not reflected in total pressure plots. The static pressure was highest at the center of the wake. They compared the variation of the first two Fourier coefficients of velocity with downstream distance and studied the averaged Fourier coefficients and scatter of the harmonic content in the rotor wake.

Reynolds and Lakshminarayana (40) studied the three-dimensional relative flow characteristics of a lightly loaded low-speed rotor wake. They found that increased loading slowed the decay rates of the axial and tangential mean velocity components and radial velocities in the wake. They found that wake width increased with loading, and that only in the far wake was it acceptable to assume a negligible static pressure variation.
Also, the axial and tangential components of mean velocity were highly asymmetric about the wake centerline, a trait which was more pronounced for increased loading. They found the wake width to increase with radial position about mid-radius and speculated that this may have resulted from large radial transport of mass, momentum, and energy.

Muhlemann (36) performed experiments that showed strong radial variation of the wake with the largest mean velocity defects and wake widths near the hub and tip regions. He also found a more rapid decay of wake width as blade loading was increased, a result verified by Ufer (36).

Kerrebrock, et al. (28) found considerable randomness in absolute exit flow angle at several radii in the wake of a blowdown transonic rotor, even when wake pressure and velocity profiles were quite sharp. They suggested the source of time dependence as random effects from the hub and tip regions influencing the entire blade span.

Shreeve, et al. (46) found impact pressures to be a jet on the suction side of the blades in the wake of a transonic rotor. Shreeve and Neuhoff (44) found the absolute velocity in the wake of a transonic rotor to have a larger magnitude on the suction side of the blades, a phenomena which was more evident at the hub where blade and flow velocities were subsonic. Schmidt and Okiishi (42) found a higher axial velocity downstream of the suction side of the blade when measured in the stationary frame, a phenomena which was, again, more pronounced at the hub region.

Ravindrath and Lakshminarayana (39) found higher total relative velocity and stagnation pressure profiles downstream of the suction side of a low-speed rotor blade, indicating that the phenomena of a suction side jet is not limited to stationary measurements. Cherrett and Bryce (5) studied the unsteady three-dimensional exit flow fields in the stationary frame of a single-stage transonic fan, comparing random stagnation pressure unsteadiness to ensemble-averaged stagnation pressure unsteadiness. They found that in the stationary frame it is possible for stagnation pressures to be higher on the suction, rather than the pressure, surface side of the passage, and for a wake in the relative frame to appear as a jet (pressure excess) in the stationary frame. In the wake region, the stagnation pressure rose rapidly from a pressure trough on the pressure surface side of the rotor wake, to a pressure peak on the suction surface side of the wake. The magnitude of the suction side peak relative to the mean level was two to three times that of the pressure trough. The point in the wake region where the stagnation pressure rose above time averaged values corresponded approximately to the position of maximum random unsteadiness.

A second stagnation pressure trough occurred on the suction surface side of the wake followed by a peak comparable to the strength of that attained within the suction surface side of the rotor wake. Wake unsteadiness was found to be three to four times that elsewhere in the blade passage, with peak unsteadiness at mid-pitch. Ensemble averaged wake stagnation pressures indicated little change in amplitude with increased compressor loading at the same speed, with the exception of the lower blade spans toward the hub where rotor inlet Mach numbers approached unity.

Colpin and Kool (6) studied the propagation of a non-uniform upstream flow field through a low-speed axial-flow compressor stage rotor. Circumferential total pressure distortion was created using a grid which was rotatable with respect to the stationary instrumentation. They found that the distortion was indicated more strongly in flow angles than velocities downstream of the rotor. They found that as a blade passed into a distortion the boundary layer on the suction side thickened due to the increase in loading. Moving further into the distorted region, the axial velocity outside of the wake increased due to increasing blockage caused by the wake. A strong reduction in the relative outlet flow angle corresponded to stronger centrifugation, or radial flow, in the blade wakes. Moving further still into the distorted region, the blade wake reached its maximum thickness indicating boundary layer separation on the suction side while the free stream axial velocity mean value increased to compensate for the additional boundary layer blockage. When reaching the distortion trailing edge, the boundary layer on the blades tended to reattach, inducing a thinner wake. After the blade passed through the distorted region, the investigators noted a reduction in wake circumferential extent and depth, as well as a slight increase in axial velocity. Colpin and Kool also noted that the flow turbulence increased at the inlet and exit of the rotor while in the distorted region. As the suction side boundary layer separated, the turbulence level suddenly grew due to the development of a large wake.

It is interesting to note that Colpin and Kool also experienced incidence angles greater than the quasi-steady stall value. A strong decrease in wake dynamic pressure corresponding to the maximum incidence angle reinforced the observation of blade dynamic stall.

6. Conclusion

The knowledge of inlet efficiency would be outcome of this review. The ramp angle varies continuously due to pressure on ramp that might change the working of the inlet in airplanes. We would also deal with the cooling channel with cooling center what would beneficial for the air cooling for what air inlet is responsible. Cooling center deals with the design of heat exchanges while Cooling channel deals with the inlet, outlet and channel design. However the study has carried in this review focused on inlet efficiency and analytical study of varying ramp angle in combination with air systems inlets.

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