

A STUDY ON PROPULSION INCITED EFFECTS ON AIRCRAFT

AERODYNAMICS

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Abstract:

When a body is subjected to an aerodynamic force, many factors affect its performance like those associated with the object, motion of the object through air and those related with air itself. Even though the body's movement through medium plays a major role, the object alone determines its consequences, of which propulsion is the crucial element to be noticed. In this paper, some propulsion induced effects on aerodynamics of aircraft are discussed. Fluid flow phenomenal descriptions of aircraft are reviewed including indications from experimental observations with empirical or analytical approaches. Particularly the problem areas reviewed are the performance losses sustained by an aircraft when hovering out of ground effect, the induced aerodynamic effects as an aircraft flies on a combination of powered and aerodynamic lift between hover and cruise out of ground effect, some results of hot-gas ingestion by the inlets of the propulsion devices when a jet airplane is on or near the ground and effects of propulsion on the performance of an aircraft hovering near the ground. These are only a few of the major factors that are emphasized to illustrate the conflicts among the spectrum of design needs. Further efforts are required for obtaining cutting edge solutions in this field.

Key Words: Aerodynamics, Propulsion, Fluid flow phenomena & Hovering

1. Performance Losses of Aircraft Hovering Out of Ground Effect:

The rated thrust of a jet engine, regardless of ordinary aircraft or for VTOL aircraft, is based on its execution with a bell-mouth inlet channel on a test stand, using the nozzle designed for the engine. The actual execution of the engine when introduced in the airplane is diminished from the test-stand rating by various installation losses. Despite each of these losses may be only a few percent of rated thrust, an precise knowledge of each is required for a practical estimate of the aircraft performance. An error of as little as 3 percent in the total lifting capacity in hover would mean a reduction of 3 percent in gross weight, which would cause a like degradation in fuel capacity. This would result in a reduction in design range of about 10 percent. There are several sources of thrust loss in hover when an engine is installed in an airplane which might be considered. These losses include inlet flow distortion, hot-gas ingestion, hot day conditions, control bleed, internal nozzle flow, base loss, static ground effect, and thrust vectoring [1]. This paper is concerned primarily with the aerodynamic lift loss in hover resulting from suction forces on the under surface of the airplane; this is commonly alluded as base loss. This paper also includes a summary of some hot-gas ingestion examinations. Finally, the aerodynamic ground effect on the base loss is discussed.

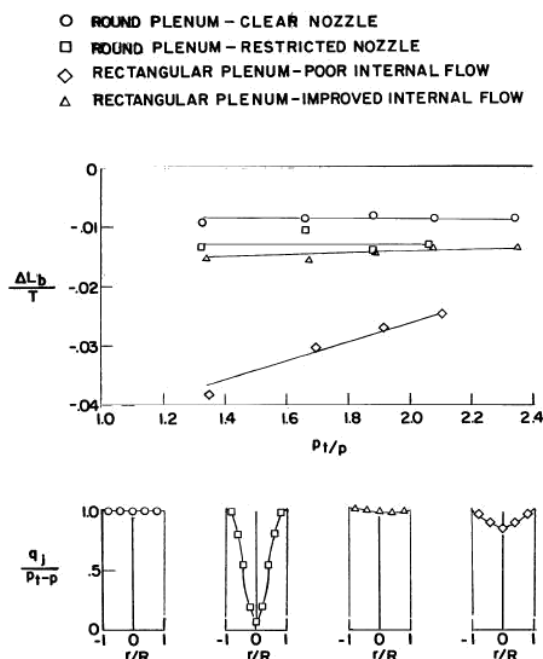
2. Jet Propulsion Induced Lift Loss for a Jet:

Figure 1: Induced loads on a circular flat plate ($S/A_j = 69.5$) and exit dynamic-pressure distributions for several single-jet configurations [4].

In a study aimed at understanding these base losses and perhaps assessing their magnitude, a plenum chamber was made which would fit inside a long rectangular fuselage [4]. In checking out this rectangular plenum chamber, the induced losses were contrasted with those obtained with a circular plenum chamber. The circular plenum chamber had a large contraction ratio between the plenum and the nozzle exit. The circular plenum chamber with a simple convergent nozzle gave a lift loss on the plate of a little less than 1 percent. The rectangular plenum chamber initially gave quite a huge lift loss. This difference in results between the two plenum chambers (both with simple convergent nozzles) caused considerable concern. It was noticed that the round plenum chamber had a flat distribution of dynamic pressure at the exit of the nozzle, while the dynamic pressure from the rectangular plenum chamber was depressed near the centre line of the nozzle. The rectangular plenum chamber also had rather poor internal flow and a great deal of separation, so that the flow from the nozzle was quite turbulent. A change in the internal lines of the plenum chamber improved the flow, as indicated by the flatter pressure profiles and the reduction in thrust loss from more than 3 percent to roughly 1.5 percent. To determine whether it was the character of the flow coming out the nozzle that determined this thrust-loss level, the round plenum chamber had a restriction placed in its nozzle which almost completely eliminated the pressure at the centre line of the nozzle. The base loss for the nozzle with the restriction raised from slightly less than 1 percent to nearly the level obtained with the modified rectangular plenum chamber. This output indicated that the type of flow coming out of nozzle has an important influence on the incited interference in hover.

An attempt was made to find a correlating parameter, in an effort to compare the lift loss to the characteristics of the jet core, the jet decay, and the turbulent mixing of the jet wake. The parameter determinately considered was the maximum dynamic pressure in the jet at different stations downstream of the exit of the jet, non-dimensionalised by the dynamic pressure at the exit of jet. The round plenum chamber with no restriction in the nozzle had the smallest lift loss and the slowest decay of jet dynamic pressure. The round plenum chamber with the restriction in the nozzle gave an incremented lift loss and a more rapid decay of jet dynamic pressure. The rectangular plenum chamber with the poor internal flow gave the huge lift loss and the swift decay of dynamic pressure. The rectangular plenum chamber with the improved internal flow gave about the same results as the circular plenum chamber with the restriction. These data indicate that a relation exists between the lift loss and the rate of decay of nozzle dynamic pressure. However, more work was required to identify the exact relation.

3. Propulsion Induced Aerodynamic Effects on Aircraft in Transition Flight:

The second piece of this paper introduces the fly actuated impacts on the plane in a cross wind out of ground effect. The streamlined impedance impacts experienced in the transition speed run amongst the hovering and traditional flight have been the subject of a substantial number of trial examinations [5] to [9]. The majority of this examination exertion has been the examination of the powers and minutes prompted on the air ship by the cooperation of the vertical planes with the free-stream air amid transition flight.

During transition flight, the jets issuing from the aircraft are swept rearward by the free-stream flow and are swiftly rolled up in a pair of vortices (fig. 2). These rolled-up vortices initiate suction pressures on the fuselage and a distribution of down-wash over the aircraft. This downwash creates an induced twist on the wing and tail and an incited camber over the length of the airplane.

There is generally a loss in lift which tends to increment with increasing forward velocity. The loss in lift is about the same with the tail off the vehicle and with the tail on. There is an increment of nose-up pitching moment in transition flight which tends to raise with increasing velocity. Because of the change in downwash in the region of the tail, an additional increment of pitching moment is incited when the tail is on.

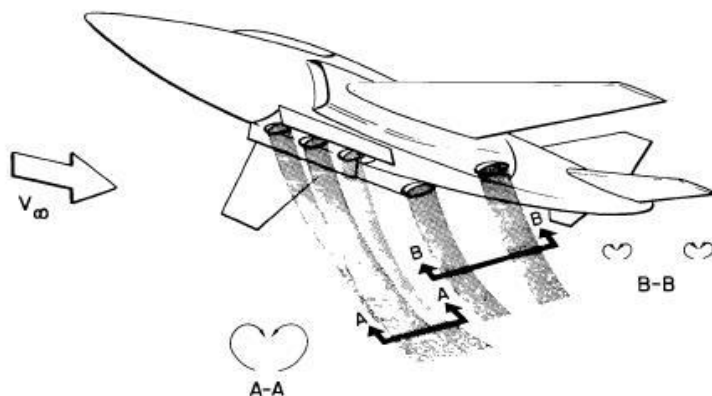


Figure 2: Jet wakes from an aircraft in transition flight roll up into vortex pairs [2].

4. Visualisation of Transition Flow Phenomena:

By means of water-tunnel flow perception, a more detailed look at the jet in the cross flow is presented in figure 3, which presents the flows induced in and around the jet. A flat plate with the free stream is shown from the left and a jet exhausting through the plate, right angle to the free stream. Near the leading edge of the plate are orifices through which coloured milk is emitted. When the coloured milk filament on the centre line of the jet exit gets to the vicinity of the jet exit, it has a stagnation point near the front of the jet and then it is swept around the jet exit. The visible portion of the jet wake indicates that some of the milk flow from the free stream is sucked into the jet. The milk flow filament adjacent to the jet passes beside the jet and is then induced upward into the non-laminar wake region behind the jet. Even the coloured milk filaments farthest from the centre line of

the exit are sucked toward the jet into the wake region. In the wake region, a considerable amount of entrainment into the jet can be observed.

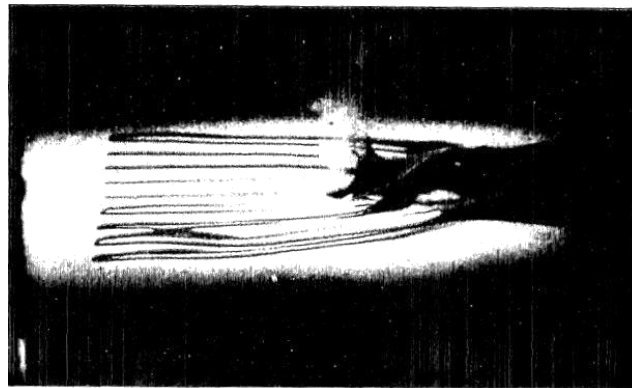


Figure 3: Photograph of the flow Induced around and into a jet exhausting normal to the free stream. (Photograph from O.N.E.R.A. Film No. 575, VOWS with large velocity Fluctuations)

5. Hot Gas Ingestion:

Hot-gas ingestion is a serious problem for jet aircraft when operating near the ground. Hot-gas ingestion is the taking into the engine inlet of the hot exhaust gases or air heated by the exhaust. It should be emphasized that the problem is not the ingestion of debased air, but the raised temperature of the inlet air.

The general stream patterns that cause hot-gas ingestion are appeared in figure 4. In still air, the fumes gases that strike the ground and spread outward to the far field present little problem as the gases will be cooled before they are recycled back to the inlets. The multiple jet setup in figure 4, in any case, can have a major issue with the fountain of hot gases that happens underneath the aircraft when the exhausts of broadly spaced engines crash subsequent to striking the ground. These quickly stream upward around the fuselage and achieve the region of the deltas while the gases are as yet hot. The other arrangement in figure 4 has a solitary engine or firmly assembled group of motors which would be required in still air to bring about low delta temperatures, since the fumes would be overwhelmed far, with twist, in any case, the fumes gases are blown back toward the channel and ingested. This impact can bring about high channel air temperatures.

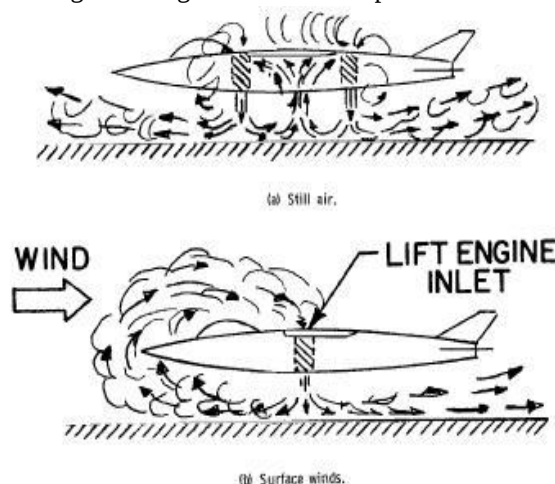


Figure 4: The general flow patterns which cause hot-gas ingestion [1].

A. Hot Gas Ingestion Due to Fountain Effect:

The fountain effect illustrated in figure 5 exists with multiple-nozzle configurations. The fountain of high-temperature air between the nozzles flows upward rapidly and is ingested by the inlets.

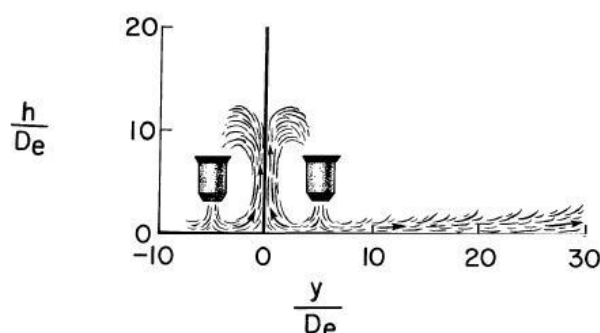


Figure 5: Sketch showing the extent of the hot-gas cloud in still air (fountain effect) obtained when multiple nozzles exit vertically near the ground [1].

For the single-nozzle arrangement in both cases, there are relatively low levels of temperature rise. In other words, with the single nozzle there is no fountain. With in-line nozzles, the jets are very close together. As a result, the up flow is not significant, and the inlet temperature rises are small. However, with the rectangular nozzle arrangement and with four nozzles on the sides of the fuselage, there are fairly large temperature rises in the inlets.

In addition to the obvious configuration variables of inlet and nozzle arrangement, the placement of the wing on the fuselage was found to be an important parameter. The effect of wing height on the temperature rise of the top inlets for the rectangular and the in-line nozzle arrangements with a zero wind condition is shown in figure 6. Inlet temperature rise is shown as a function of model height above the ground in equivalent nozzle diameters. The wing in a low position is seen to greatly reduce the inlet air temperatures at all test heights of the rectangular nozzle configuration, but has little effect on the in-line nozzle configuration, which has very low inlet air temperatures with both wing positions. Observations of smoke from the exhaust nozzles indicated that the low wing caused the upward-flowing hot gases to be deflected outward and away from the inlets.

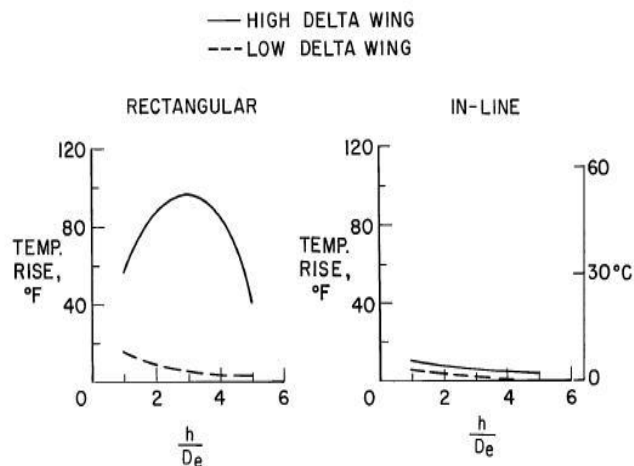


Figure 6: Effect of wing height on air temperature rise in top inlets caused by the fountain effect on two nozzle configurations in still air [1].

B. Hot Gas Ingestion Due to Cross Wind:

The aircraft has a solitary nozzle exit and a solitary channel in the best and is working in a 5 to 8 knot cross wind. At time zero, the nozzle is deflected straight down from an underlying rearward redirection of 25° and oil is infused into the hot fumes stream to deliver smoke. At once 0.2 of a moment later, the smoke is advancing outward. At 0.4 of a moment later it begins to rise, and at 0.6 of a moment later the cross breezes are beginning to blow it back to the vehicle. When 1 second has passed, the vehicle is for all intents and purposes drenched in the fumes gas. This quick temperature rise tends to cause compressor slow down, which might be a more major issue than the greatest level of temperature.

These and other information are condensed in figure 7. Results are exhibited for the fundamental setups of the Langley show with side inlets - the single exit, the in-line nozzles, the example of rectangular and side inlets. The initial two courses of action indicate next to no temperature ascend with no wind, however the second two plans demonstrate huge temperature ascends with no wind. For examination, comes about because of the Ames-Northrop display are shown at the base of the figure for the no-wind case. On this design, both the lift engine inlets in the front and the lift-cruise engine deltas at the back experienced recognizable temperature rises. With either a head wind or a side breeze, each of the four of the Langley setups have a huge issue with inlet temperature rise.

BASIC CONFIGURATION	INLET AIR TEMPERATURE RISE					
	NO WIND		HEAD WIND		SIDE WIND	
	°F	°C	°F	°C	°F	°C
	20	11	160	89	160	89
	10	6	60	33	60	33
	140	78	180	100	200	111
	90	50	110	61	120	67
	150	83	—	—	—	—
	100	55	—	—	—	—

Figure 7: Summary of test results obtained for large-scale hot-gas ingestion models [3].

It ought to be expressed that hot-gas ingestion is an intense issue for jet air craft. An incredible arrangement is thought about the flow fields and reasons for ingestion, and after effects of current examinations utilizing small scale models will add further to this information. It is accepted, in any case, that more work will be required before the ingestion attributes of a specific setup can be anticipated precisely. And still, at the end of the day, the ingestion issue won't be settled.

6. Propulsion Induced Effects during Hover in Ground Effect:

There are propulsion-induced effects when a jet-lift aircraft is hovering in ground effect. Figure 8 shows schematically how the ambient air is entrained around the lower surface of the vehicle into the jet; it then strikes the ground and flows outward as a wall jet. The entrainment induces a download on the vehicle. These phenomena are well understood for the case of a single jet. Downloads can be calculated by using the empirical methods of L. A. Wyatt [10]. The data shown in figure 9 are for the X-14A airplane, which has two jets placed close together under the centre of gravity. They are close enough together to be considered a single jet. The full-scale and model data are in good agreement with the calculation.

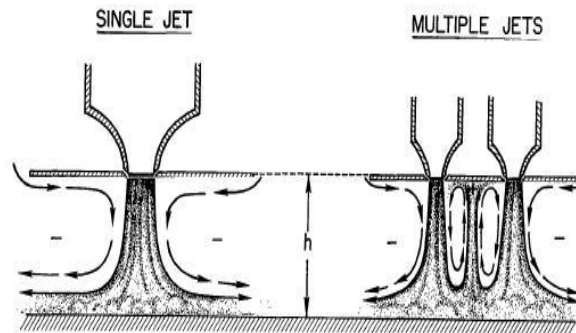


Figure 8: Sketch of the jet-induced flow for single and multiple jets exiting vertically near the ground [2].

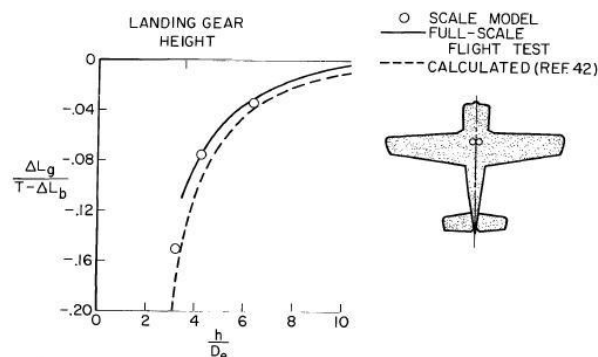


Figure 9: Jet induced lift loss near the ground for the X-144 airplane as given by small-scale model data, flight data, and calculated estimation [2].

Unfortunately, the phenomena for the multiple-jet case are not so well understood. In figure 8 the flow characteristics of the single jet are contrasted with the flow of the multiple jet. The primary difference is the fountain of hot gas between the two jets. This up flow between the jets causes large positive pressures on the lower surface of the fuselage. There is also a circulatory flow between the jets and the fountain. To get a better understanding of this fountain effect, the results of some investigations of the up flow are presented in the following sections.

7. Characteristics of the Up Flow from a Pair of Nozzles:

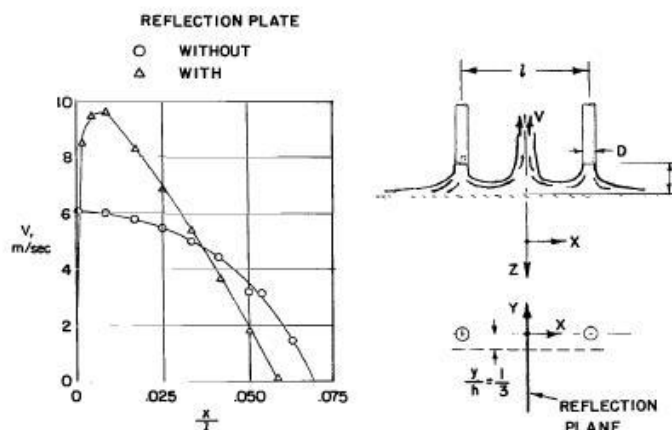


Figure 10: Effect of a reflection plane on the measured up flow velocities in the fountain flow caused by two jets exiting vertically near the ground. The nozzles were at a height (h/D) of 3 and the up flow velocities were measured in the nozzle exit plane at a lateral distance (y/h) of $1/3$ [11].

The results of some work done in Germany by Hertel [11] are presented in figure 10. The sketch shows the two nozzles exhausting near the ground with an up flow. Starting at the centre line between the two jets, the velocity of the up flow was measured with both jets operating; these results are indicated by the circles. There is a gradual drop off in the up flow velocity from the line of symmetry. Then a reflection plane was placed at the plane of symmetry. The velocities were measured and plotted as the triangles. There is a large up flow velocity at the line of symmetry which drops off sharply. This shows that the use of a vertical reflection plane is not appropriate for measuring data with jets in ground effect. Further, the results show that there is not a true line of symmetry; instead, there is quite a bit of mixing and interaction between the up flows from the two jets.

The reflection plane also has an effect on the inlet temperature rise. The two jets, impinging on the ground with a fountain between them, are moved from a height of 2 diameters from the ground to a height of 10 diameters above the ground. When no reflection plane is located between the two jets, the inlet temperature rise is large at a height-diameter ratio of 2. It drops off sharply and approaches zero at a height-diameter ratio above 10. In contrast, with the reflection plane, there is a temperature rise of about 30° F (170 C) close to the ground, which increases steadily as the inlets move away from the ground. When the nozzles are close to the ground, high velocities on the reflection plane carry the gases up above the inlet and disperse them away from the inlet. Consequently, inlets near the ground are not influenced by the hot gases when the reflection plane is in place. As the exits of the jets are moved away from the ground, the inlets gradually move into the region where these hot gases are carried up, furnishing results in sharp contrast to the data without the reflection plane.

8. For Multiple Jet Configurations:

For a given range of heights, there is a reduction of lift loss with a multiple-jet engine as the exits are spaced farther apart and thus enlarge the model area that experiences favourable pressures from the fountain of jet gases reflected up from the ground. However, this increase in spacing would be expected to worsen the hot-gas ingestion problem because of a deduction in shielding of the inlets and the higher sensitivity to cross winds.

The results for many different multiple-jet configurations have been observed [12] to [15]. They indicate that the magnitude of lift interference due to ground effect in hovering flight is dependent on the model configuration as well as the nozzle arrangement. Therefore, in spite of the fact that these two sets of data seem to show consistent trends, attempts to correlate the effect of ground on the interference lift for multiple-jet configurations has not as yet produced acceptable results .

9. Concluding Remarks:

The material introduced in this paper has concentrated on many aspects of the induced effects on aircraft aerodynamics in hover and transition flight which are caused by the interference of wakes from relatively high-disk loading aircraft propulsion devices. Only a few of the key factors discussed are emphasized to illustrate the clashes among the spectrum of design requirement facing the airplane designer or to illustrate the state of the art of the solutions to some of the problems.

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