70/INT AERO/27

A DESCRIPTION OF THE RUMBLING, BUZZING, AND BANGING WITHIN THE ARROW PROPULSION SYSTEM

W.B. McCarter October, 1958

AVRO AIRCRAFT LIMITED

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A DESCRIPTION OF THE RUMBLING, BUZZING, AND BANGING WITHIN THE ARROW PROPULSION SYSTEM

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REPORT NO. 70/INT AERO/27
SHEET NO. 1

AIRCRAFT:		PREPARED BY	DATE
ARROW 1		W.B. McCarter	Oct., 1958
		CHECKED BY	DATE

SUMMARY

The noises emanating from the Arrow propulsion system are due to aerodynamic flow-breakaway. Rumbling is the separation of airflow from the outboard lips of the intake, buzzing is initiated by the separation of the turbulent boundary layer from the ramp surface and internal lip profile, and banging is initiated by the separation of engine airflow from the compressor blading.

Each can be heard by the pilot and vary from the low intensity rumble to the high intensity crack of an explosion.

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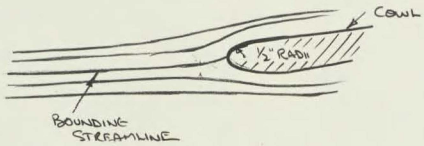
SHEET NO. 2		
AIRCRAFT: ARROW 1	PREPARED BY: W.B. McCarter	DATE: Oct., 1958
	CHECKED BY:	DATE:

RUMBLING

Rumbling can be expected when there is flow breakaway due to excessive angle of attack on the outboard lip of the intake. The lip profile was designed to give minimum drag contribution at supersonic speeds and, at the same time, acceptable pressure and velocity profiles within the internal flows. Thus the profile is 'supersonic' on the outer surface with 1/2 inch leading edge radius blended into a slender cowl (the cowl angle is always less than 5^{o}) whereas the internal profile is a blunt ellipse with 22% area contraction from lip station to throat.



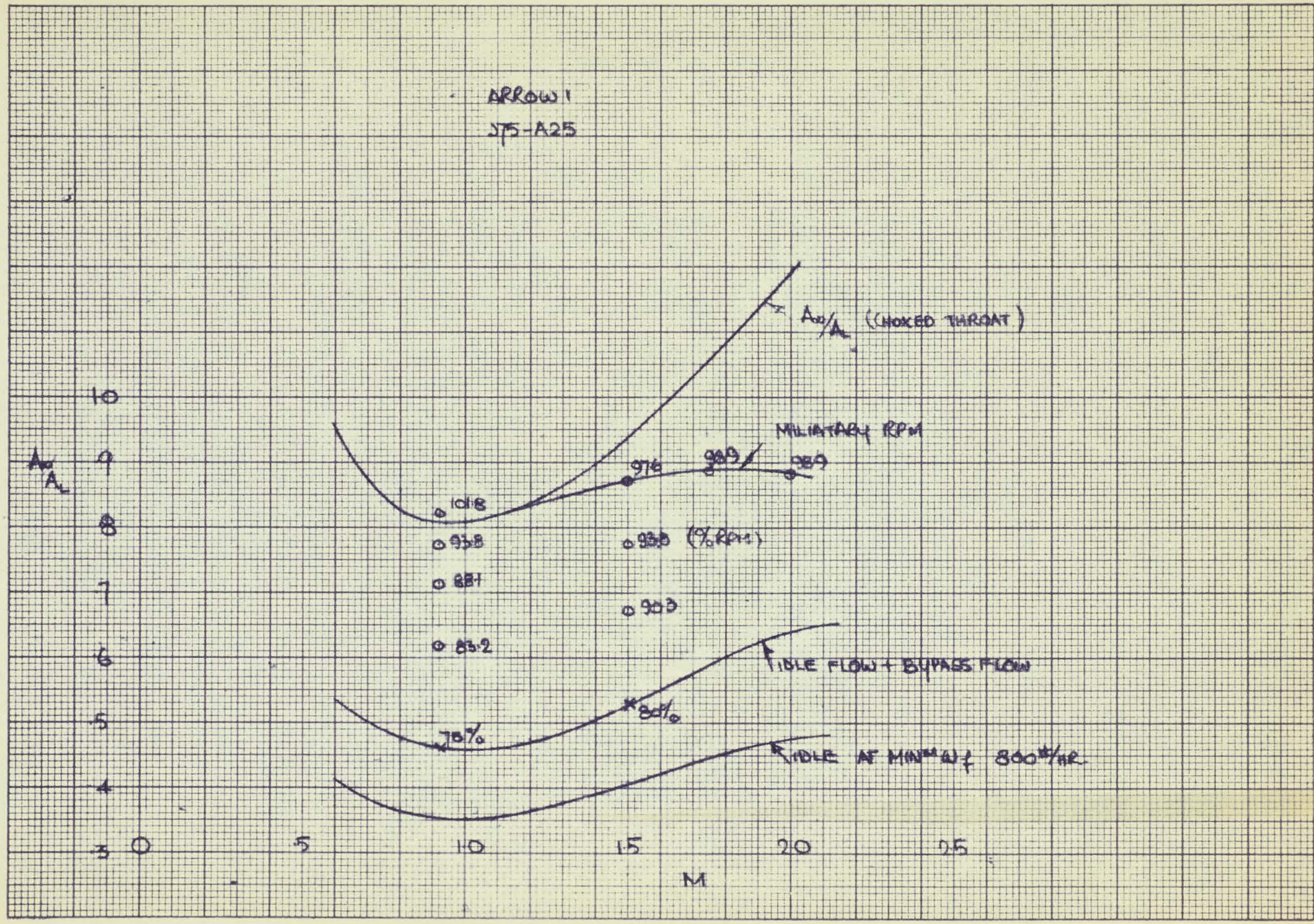
The angle of attack of the lip is defined by the bounding streamline which encloses the flow entering the intake. At reduced RPM this stream tube area decreases and thus for a fixed geometry intake the flow angle in the region of the lip must increase.

The relation of the ratio of free stream tube area to intake frontal area, with Mach Number at the same RPM (see attached graph) is such that breakaway is most likely to occur at reduced RPM in the Mach No. range $.8<M<1.2$.

Model tests indicate (Ref: NACA RM A56C06) that for the geometry of our intake breakaway should occur at stream tube ratios less than about .8. The separation 'bubble' (is the cowl area over which the separated flow exists) increases for reduced RPM below this stream tube ratio of .8 during which time the rumbling noise will rise in intensity. Arrow aircrews report uncomfortable rumbling near idle RPM during descent which lies within the critical Mach Number range $.8<M<1.2$.

Because of the increased pumping of the Iroquois and enlarged bypass of the Arrow 2, (the lip geometry is unchanged) this rumbling may never occur on the production aircraft.

This aerodynamic noise caused skin cracking and the loss of a few rivets in the region of the separation bubble. The skin material was changed and stiffened to eliminate future damage. The rumbling will continue but should not cause any anxiety to the pilot.


ARROW 1
J75-A25
A_0/A_L (CHOKED THROAT)
MILITARY RPM
(% RPM)
101.8
93.8
88.1
83.2
97.6
98.9
98.9
93.8
90.3
IDLE FLOW + BYPASS FLOW
80%
78%
IDLE AT MIN^m W_f 800#/HR
A_0/A_L
10
9
8
7
6
5
4
.3
0
.5
1.0
1.5
2.0
2.5
M

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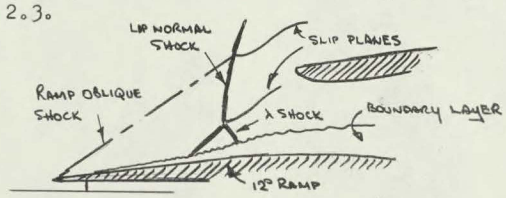
BUZZING

Buzzing of the intake can only occur when the ramp boundary layer separates due to the interaction of the ramp shock structure. The lip normal shock wave is sufficiently strong to separate the ramp surface turbulent boundary layer at aircraft Mach Number 1.76. This wedge-shaped separated region induces a lambda shock wave which at low inlet mass flow ratios becomes unstable. A fluctuating static pressure within the duct results, which is defined as buzz.

High speed film shows the above mechanism at work. The slip plane from the intersection of the lambda shock and lip normal shock interacts with the turbulent boundary layer on the duct wall. This boundary layer separates choking off the duct flow, the normal shock moves upstream with explosive velocity spilling the excess air around the lip. The slip plane moves upstream as well giving relief from the interaction on the duct wall. The duct mass flow can now increase but contact is again made between the slip plane and duct wall and the oyole begins anew.

Thus the buzz-free range of engine RPM was expected to be 100% at less than M 1.76 and to progressively decrease at increased Mach Number until it would be impossible to operate the J75 at full RPM when the ramp oblique shock wave enters the intake at M 2.3.



Tests at mass flows oonsistent with the full 100% range of RPM were made in the 8 x 6 foot supersonic wind tunnel at NACA Lewis Laboratory at Mach Numbers to 2.1 at Reynold's Number of 25 million on a 1/6 scale model of the Arrow 1 geometry. This model was an accurate replica of the aircraft right back to the engine compressor face including the perforated ramp bleeds, diverter bleed beneath the ramp, and bypass around the engine.

As a direct result of these tests the buzz threshold of the Arrow 1 was found to be M 1.81 at windmilling RPM and M 1.87 at idle RPM in straight and level flight, at 50,000 ft. The test data was then used to size the Arrow 2 intake and bypass to allow buzz-free flight at windmilling RPM below M 2.0. (See attached graphs).

Because of the improvement of buzz threshold with increasing angle of attack (the intake has a negative angle of attack relative to the wing) it is suggested that should the pilot find himself with a buzzing duct that he increase the aircraft normal acceleration to 2.5 g.

A fuller analysis of the buzzing phenonema is found in P/POWER/66 and 72/INT AERO/8 and is suggested reading for Arrow aircrews.

8 July 1956

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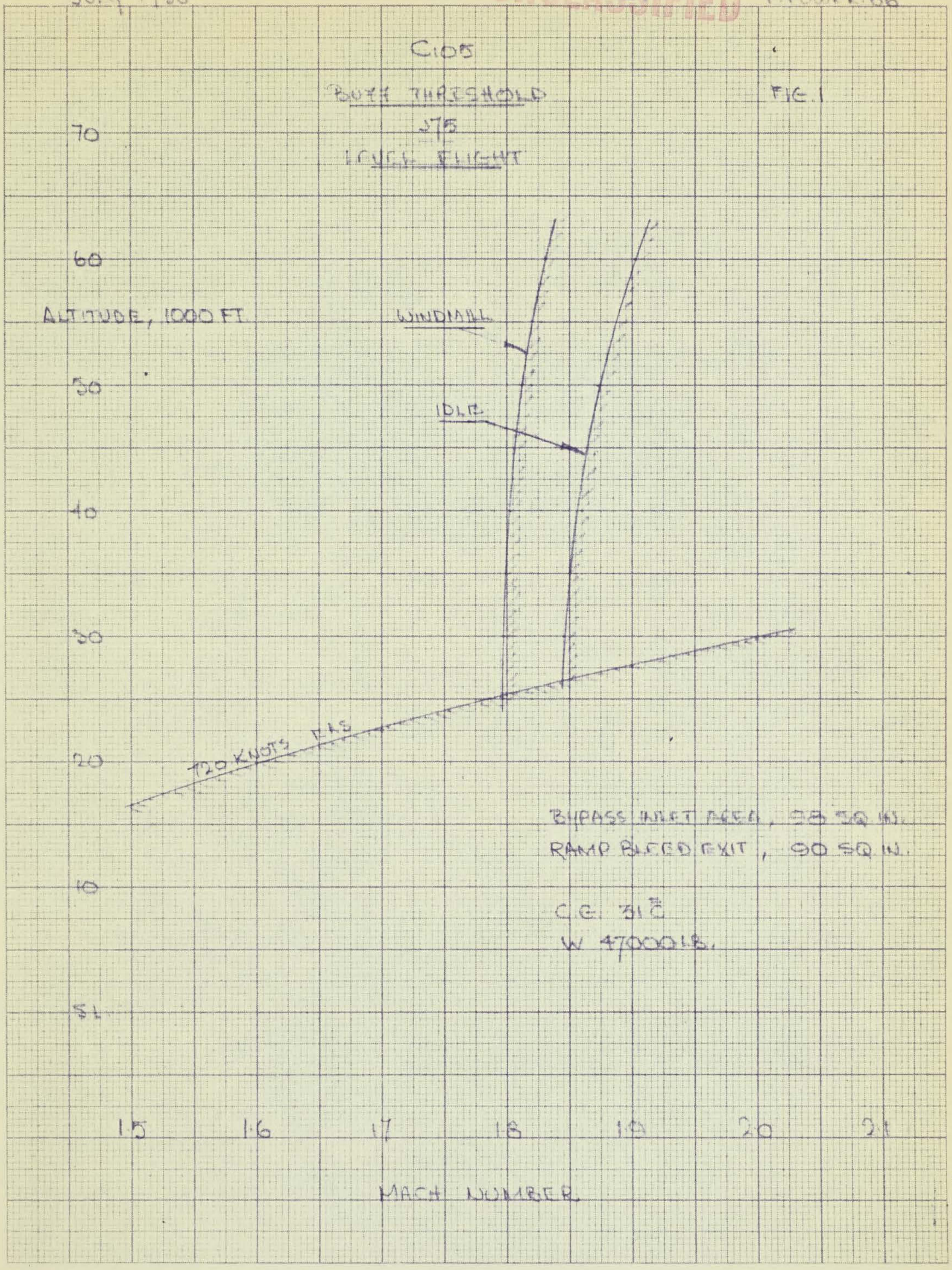
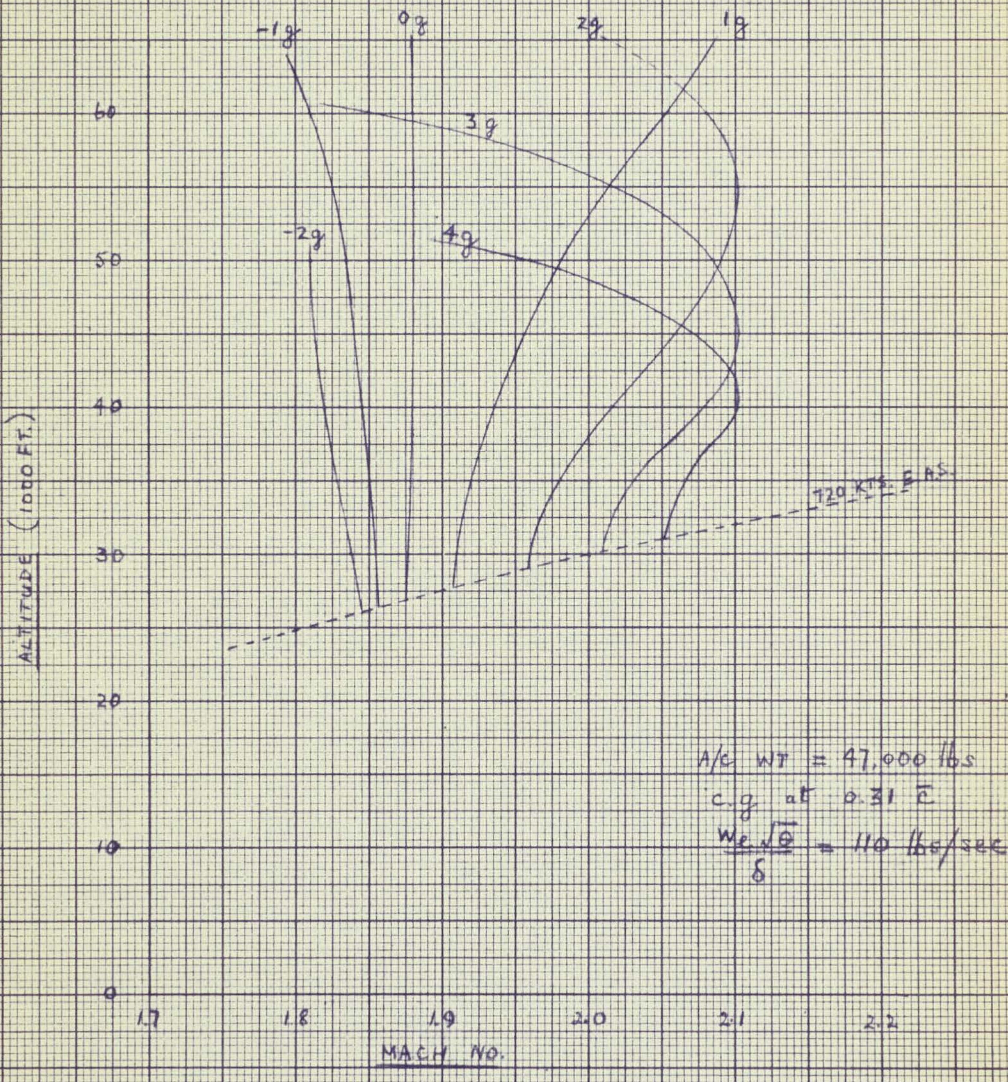
P. POWER. 66



IROQUOIS (SERIES 2)

WINDMILLING BUZZ BOUNDARY

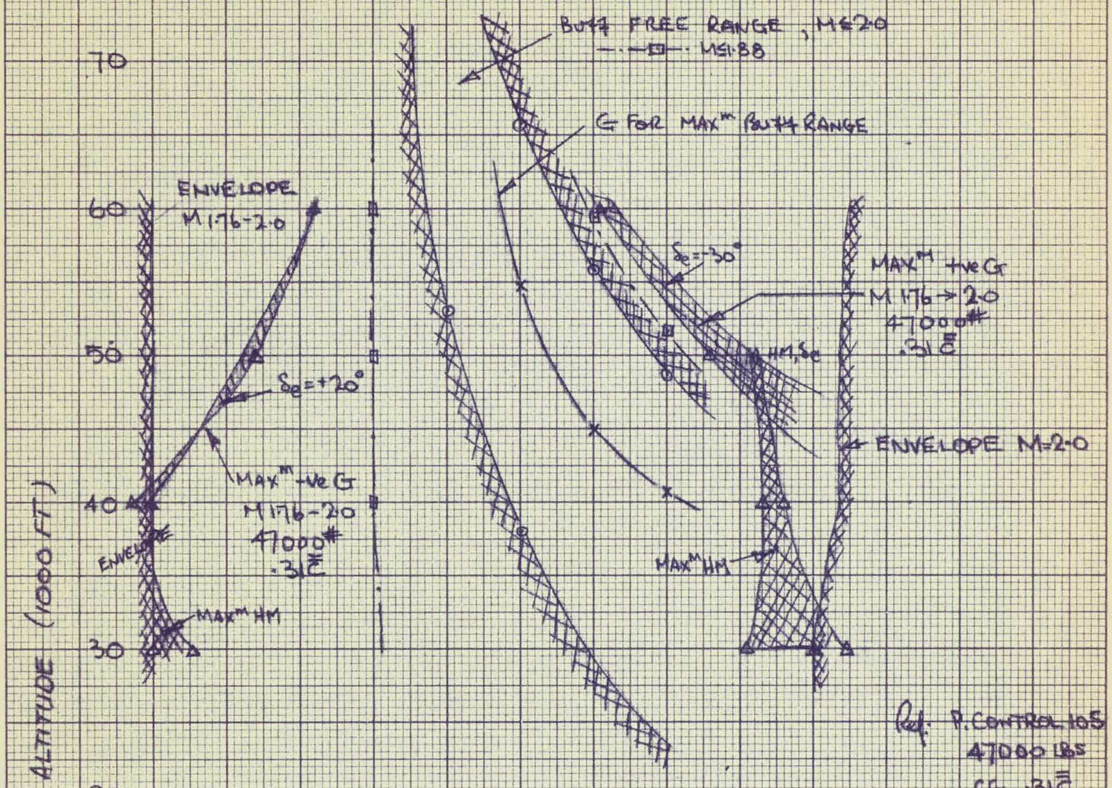
FIG 3.



72/INT DF20)8

WINDMILLING BUZZ BOUNDARY
ARROW 2

FIG 4



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PILOT INSTRUCTIONS:

a) WHEN IN BUZZ, PULL +2.5 G.

b) BUZZ CAN ONLY OCCUR WITH A WINDMILLING ENGINE ABOVE M1.76. THIS M IS ONLY POSSIBLE ABOVE 24000'.

c) THE WEIGHT OF 47000# IS THE LEAST POSSIBLE WEIGHT THE ARROW 2 CAN BE AT AT M2. INCREASED WEIGHT IMPROVES BUZZ RANGE.

d) C.G. IS EXPECTED to BE FORWARD OF .31c̄. FORWARD MOVEMENT IMPROVES BUZZ RANGE.

-4 -3 -2 -1 0 1 2 3 4 5 6 7 8

NORMAL ACCELERATION (G)

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BANGING

Noise of high intensity will be heard by the pilot when the engine surges or when a high pressure pulse passes along the cockpit.

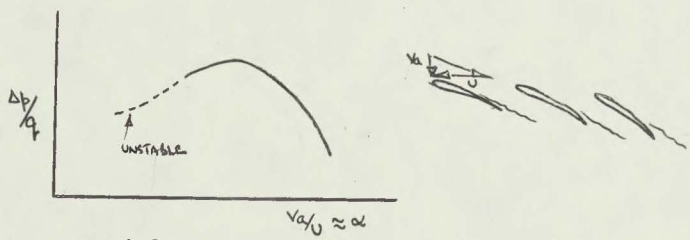
Surge is possible on all air-breathing engines, compressors, supercharges etc. Proper design of fuel controls, for example, demands that the engine is never operated beyond the surge regime. The broad range of engine conditions demanded of the engine, i.e. flight at sea level and extreme altitude, takeoff speeds and Mach 2, make it difficult to properly set the fuel controls for efficient operation within the surge-free regime.

Compressor blading stalls for the same reason that aerofoils stall, i.e. because of excessive angle of attack. The effective angle of attack of the blading is the resultant direction of flow relative to the blade chord due to the axial airflow vector and the radial airflow vector due to engine RPM.

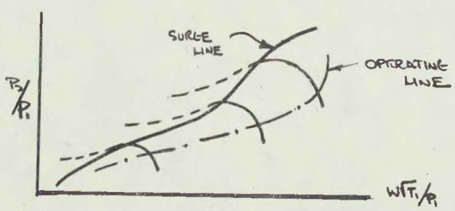
Thus the effective angle of attack increases at the time that the engine airflow is reduced for the same RPM.

When the flow separates fromthe blading thereis a consequent loss in pressure within the compressor staging which leads to a noise whose intensity depends directly on the severity of the flow breakaway. The noise, to quote Pratt and Whitney Information Letter No. 4, may vary from inaudible roughness to cannon fire.

For the individual blading the flow characteristic is of this form:



For the compressor as a whole:



We must then consider what will reduce this surge margin.

1) The stall or surge margin is reduced at low Reynold's Number. Because the R.N. is reduced by a factor of 10 in going from S.L. to 60,000', it can be appreciated that compressor stall is most likely at extreme altitude.

BANGING (Cont'd)

The effect of reduced R.N. is to allow laminar flow over the first stage of the compressor. Laminar flow is much more sensitive to separation due to pressure disturbances. A well-known example of this sensitivity is the problem in retaining laminar flow on the World War II laminar-flow-wing. A dust and inseot-free surface was necessary. Even though the R.N. may not be reduced to a value to allow laminar flow the increased friction and boundary layer thickness reduce the airflow for the same RPM thus increasing the blading effective angle of attack. This in itself will reduce the surge margin. Smooth operation of the throttle at altitude is essential.

2) Inlet distortion reduces the surge margin in two ways. It increases the effective angle of attack of the compressor blading by reducing the engine airflow for the same RPM and at the same time superposes pressure disturbances.

Although the steady state distortion levels at the compressor face are always well within the limits allowed by the engine manufacturer, they are worst at high Mach Number at full RPM. (Ref. NACA RM E56J01).

Further aggravation of the distortion levels by chopping throttle and superposing transient pressure pulses may put the engine into surge espeoially at high Mach Number.

3) Low temperatures tend to make the J75 operate closer to the stall margin to quote P.W. information letter No. 4. This is a characteristic of the operating line which is built-into the design when the LP:HP compressors are matohed and can ocour at low or high RPM.

When the engine has stalled at low RPM increasing the RPM may put the engine back into stall-free operation but if the engine continues to operate unstably the increased intensity of the stall may be sufficiently severe to cause structural failure. Reducing RPM may not eliminate surge but will reduce the intensity of the pressure fluctuation and cause the aircraft to lose both airspeed and altitude thus reducing the pressure load.

In a compressor there is an adverse (i.e. increasing pressure) gradient whereas in the turbine the reverse is true. Thus disturbances to the flow in the compressor are obviously more likely to cause separation and thus we must conclude that the compressor is more likely to surge than the turbine.

It follows from the above discussion that although it may be difficult to schedule the engine control system to give a stable operating line under steady state conditions, it is during transition from one operating point to another that there is great danger of exceeding engine limits.

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BANGING (Cont'd)

Because breakaway reduces the effective area between blading the airflow is choked off and the excess airflow expelled with explosive velocity carrying with it the intake shock structure.

The intake normal shock which normally, even at idle RPM, is behind the pilot is carried forward past his ear. The amplitude of the pressure pulse is equal to the static pressure rise through this normal shock wave and is equivalent to approximately 178 db sound pressure level at M 1.75 at 53,000' on the exterior of the cockpit. Dissipation of 30 db due to aircraft structure means the pilot is subjected to a noise equivalent to the crack of a shotgun.

Because compressor stall normally has a frequency about half the engine RPM and the noise heard by the pilot was approximately 1 cps the author suggests that the noise heard by the pilot was the shock pressure pulse moving past the cockpit when the compressor surged. The first crack was the shock moving upstream and the second when the shocks returned when the pilot increased RPM putting the engine out of the surge regime. The 1 cps frequency was the response time of the pilot to the stall.

Because of the rugged construction of the J75 no damage has been reported due to surge. However, as the Arrow is flying at higher altitude and greater Mach Number than aircraft presently incorporating the J75 the possibility of surge is greater and the amplitude of the resulting pressure pulse within the engine is greater still.

Consequent to the reduction of flow through the engine due to compressor stall, a much increased flow will be forced through the bypass. A sudden negative pressure pulse will pass along the bypass and could tear the insulation blanket from the airframe.

CONCLUSION

The noises emanating from the Arrow propulsion system are due to aerodynamic flow-breakaway. Rumbling is the separation of airflow from the outboard lips of the intake, buzzing is initiated by the separation of the turbulent boundary layer from the ramp surface and internal lip profile, and banging is initiated by the separation of engine airflow from the compressor blading.

Each can be heard by the pilot and vary from the low intensity rumble to the high intensity crack of an explosion.

The anxiety of Arrow aircrew will be minimised by the prior-knowledge that structural damage due to rumbling has been eliminated and that it is largely up to the pilot to prevent the more serious phenomena of buzz and banging.

Generally speaking, rumble is a transonic speed flow problem at reduced RPM, buzz is a high supersonic speed flow problem at reduced RPM, and banging is a high altitude flow problem during handling exercises.

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