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ABSTRACT

The work on ACT for civil transports performed over some ten years at BAe Weybridge is summarised under the two main headings

Relaxed Stability
Load Alleviation

The work has culminated in a flight demonstration of systems to perform each function using the Company's research aircraft, a BAC 1-11 with registration G-ASYD.

The reasons for the salient features of the systems employed are discussed. The main conclusions from the demonstration are outlined.

Introduction

Since about 1972, British Aerospace has been studying Active Control Technology for civil transports as one line of research aimed at improving their profitability. (Reference 1).

This paper outlines the work on the two main lines of investigation

Relaxed Stability
Load Alleviation

which has culminated in a flight demonstration programme.

The work was part funded by DTI.

Other studies included flutter suppression but are not discussed here.

Relaxed Stability

The aim of the research was to determine the reduction in horizontal tail size which followed from allowing the centre of gravity to move aft beyond the limit normally set by aircraft stability considerations and to design and check out a pitch control system which would restore the aircraft's stability characteristics. Such a system would also provide the handling qualities.

It was realised from the outset that the control system introduced gave the possibility of implementing new (and unfamiliar) handling characteristics and that these could be made advantageous in their own right.

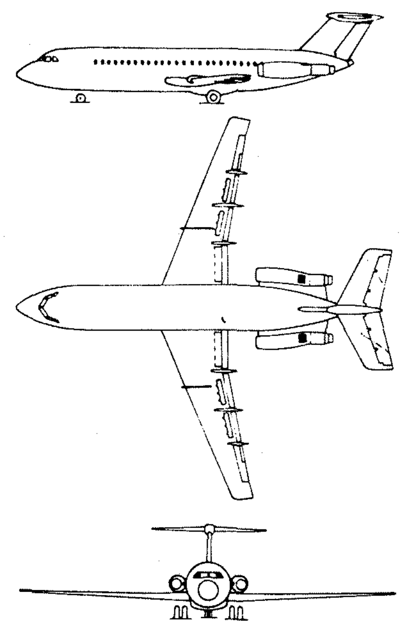
The system devised and subsequently proved in flight is called Command Augmentation System (CAS) and would typically allow a reduction in tailplane size by about 20% if the aft CG position be allowed to be as far aft as the manoeuvre point (ca. 52% SMC) yielding about 1-1.5% reduction in D.O.C. The kernel of the system is described by the following equation:

$$\eta = K_1 (q + K_2 \Delta x)$$

$K_{1,2}$ are constants, η is elevator angle, q is pitch rate; Δx is column movement.

It can be seen that it is essentially a pitch rate demand system requiring as inputs stick position, pitch rate and elevator position. It does not make use of normal acceleration.

The system was extensively studied with data from the BAC 1-11 aircraft Figure 1 and its successor the BAC 3-11(which was never built) both by calculation and by using a fixed base simulator.



1-11 475 G-ASYD GENERAL ARRANGEMENT

Fig. 1

The developed ideas were tried out initially using the RAE's BAC 1-11 equipped with a 'versatile autopilot' (a programmable analogue computer). During this operation it was demonstrated that the aircraft was quite flyable for durations of the order of 30 minutes with the CG simulated to be at the manoeuvre point and the system switched off. This was an essential point in that it allowed the construction of a CAS system for experiment and test on the Company's research aircraft (the BAC 1-11 G-ASYD) using only a single channel, since in the event of passive failure at extreme aft CG, the aircraft could be

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flown safely for sufficient time to restore the CG or reduce speed. The tailplane was not modified.

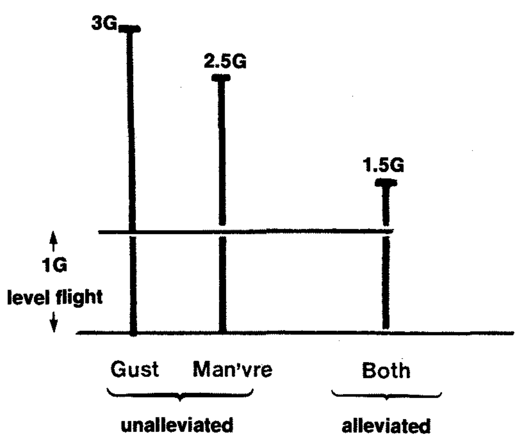
The implementation of the system and the results obtained are described later under the Demonstration heading.

Load Alleviation - General

The research was directed towards reducing the incremental wing loads resulting from both manoeuvres and gusts. After some preliminary work, a research target was set of reducing the (total) bending loads on the wing by a half as a result of using a wing load alleviation system. This target was seen as severe but probably attainable.

The benefit from so doing results from a reduction in wing weight (including the centre section) which, for the case of halving the wing bending load everywhere on the wing, is in the region of 20%, which translates into about 1.6% reduction in DOC if the aircraft is fixed in size or about 2.6% on DOC if the aircraft is scaled.

For the typical transport the wing shear and BM which form the design case is almost always a gust case and some 20% higher than that from the 1.5 excess G manoeuvre case. Hence a gust load alleviation system can be usefully installed without a corresponding manoeuvre load alleviation system, up to a 20% capability but beyond that both are needed. In particular to reduce the design load to a half requires a reduction in the incremental gust load by 3/4 to 1/4 approximately and the incremental manoeuvre load by 2/3 to 1/3. This is illustrated in Figure 2.



	Total	Increment
Gust	50%	75%
Manoeuvre	40%	33%

ALLEVIATION TARGET

Fig. 2

Load Alleviation for the gust case can be achieved by deploying motivators to destroy the incremental load: in the manoeuvre case the total incremental load must be preserved or else the manoeuvre will not be achieved. Hence the manoeuvre system must deploy a load transference mechanism, using motivators for increasing load at the root and reducing load at the tip.

The decision was taken early on to study only traditional controls (ailerons, flaperons, spoilers) as motivators. Whilst the early work showed that with somewhat larger controls than would otherwise have been used and operating them through larger angles, the 50% reduction in total load could be achieved, considerations of the effect of system malfunction and the consequent need for a higher reliability than was judged to be available in the medium term, led fairly soon to a cutback of the target to 33.3% reduction in load (50% in increment). This was the standard set for the subsequent work.

The reasoning for the choice of a 1/3 alleviation system lies in the parallel with civil aircraft regulations defining the strength required following a crack in primary (fail-safe) structure. Civil structures carry a 1.5 safety factor meaning that the maximum load expected to be encountered by a fleet of the type operating for its life time (the proof or limit load) is to be factored up by 1.5 to make the design load. The extra 50% in strength is to cover any deficiencies in design and manufacture that might have occured. The rules allow that an aircraft may continue to operate with a crack in the structure which impairs its strength to the proof level until the next inspection.

For the load alleviation considerations it was argued that if the strength, in the event of failure of the system to operate when required, was equal to proof load (or greater) then by analogy with the cracked structure rules the design would be satisfactory irrespective of any arguments about system reliability. Continuing the analogy it could be said that the load alleviation system plays exactly the same role in the overall scheme as does the extra structural material to get this 50% extra strength; but the load alleviation system is better in that it can be made to signal its own health state.

However, hard overs (runaways of the actuator or response to false full scale signal demands) must be considered (whether the aircraft uses load alleviation or not) and these require probabilistic evaluations.

Manoeuvre Load Alleviation (MLA) Studies

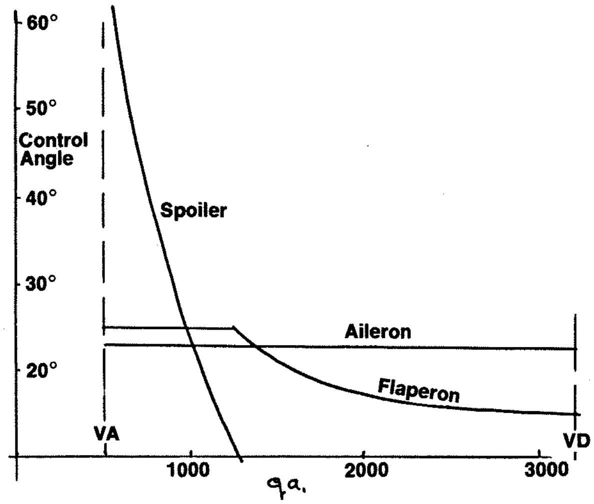
It is clear that although an MLA system could in principle limit the excess G available to a pilot for manoeuvring to any value (the care-free manoeuvring facility desired by the military), no study of what value should be used was made. Accordingly the 1.5 G incremental case was accepted which extends over the full flight range.

The MLA studies uncovered only one difficulty - which could be limiting in a specific design.

The difficulty exposed is obvious in that the dynamic pressure at V_A is low and therefore high control angles are required to achieve the alleviation forces required. Larger control surfaces than normal will certainly be needed to achieve even the 1/3 alleviation target. Since

MLA involves a transference of load, both an outboard and an inboard control are needed operating in opposing senses.

Figure 3 indicates that an MLA system must make provision for the maximum control angles required to be varied with speed.



CONTROL ANGLES TO ACHIEVE ⅓ ALLEVIATION IN MANOEUVRES

Fig. 3

An MLA system could be activated by stick movement or normal acceleration. These studies assumed an accelerometer close to the CG as the sensor which appeared to be completely satisfactory. This accelerometer was shared with the gust system (GLA) described later.

The signal from the accelerometer was split into a component to drive the MLA and a component to drive the GLA. The split was made on a frequency basis, that component below about 0.7 cps driving the MLA and the part above, the GLA.

Normal actuator rates were shown to be quite satisfactory.

The control angles for the MLA depend upon speed, Mach No. and aircraft weight, requiring a comprehensive gain scheduling facility which naturally leads to a digital implementation.

For an aircraft with even moderate sweep an MLA system will be statically destabilizing. For the target levels of MLA in these studies, the reduction in static stability was deemed such that some measure of compensation would be necessary.

In the Demonstration of the MLA system on the BAC 1-11 described later, this compensation was provided by the CAS.

Gust Load Alleviation (GLA) - Studies

The contemplation of a GLA system raised a host of questions amongst them

- How useful would an outboard aileron be, bearing in mind its aeroelastic effectiveness, since the gust case is a high speed case at V_c (or perhaps V_{RA}).
- To what extent would a spoiler be useful bearing in mind that, as normally installed, it is a lift destroyer only and probably a highly non-linear device.
- How 'sharp' is the sharpest gust that has to be catered for and can any time warning (phase advance) be used.
- Can the system be made gust pattern insensitive.
- Should the objective be to alleviate both the up and down bending loads.
- Should the objective be to reduce the static loads or the fatigue loads or both.
- What are the atmospheric characteristics against which to design, loosely referred to as 'gusts' or 'turbulence'.

Some immediate opinions were available as follows.

Ailerons would be useful but at about V_c their root BM effectiveness typically would be about 1/4 and therefore they would not suffice alone. Accordingly spoilers would have to be considered but would have to be shown by test to be useful bearing in mind the likely operating rates.

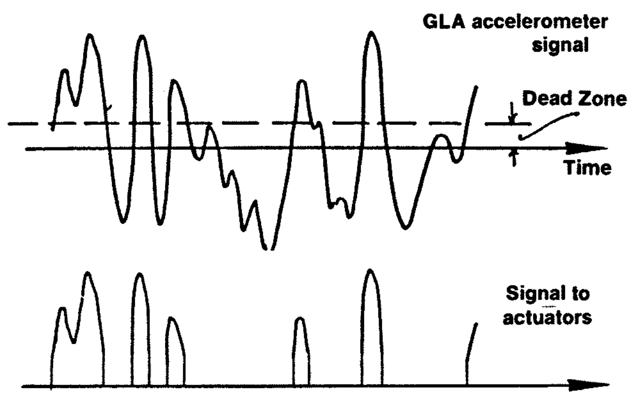
Irrespective of the detailed atmospheric description, a 'sharp edged' gust implies a fast acting GLA system, very different in response time from the MLA system. A first order estimate was easily made. If the 100 ft (12.5 chords) 1/2 wave length of the current regulation pertained and if the full spoiler angle of say 50° was to be used, then at a cruise speed of 800ft/sec the 100 ft is traversed in 1/8 sec and the mean rate is 50° in 1/8 sec or 400° sec with a peak rate some 30% greater (as for a 1-Cos shape) ie., 520°/sec. This compares with typically 50°/sec for ordinary actuators. However it was early recognised that the gust descriptions (isolated gust and continuous turbulence) were in reality recipes and of doubtful value in defining real atmospheric events for GLA design. In particular, to avoid designing a system which, although satisfactory for a specific pattern, eg., a 1-Cos gust of 12.5 chords 1/2 wave length, would not be satisfactory for some other, the system was conceived as one which caused the controls to follow the demand signal, indicative of the gust or turbulence variation with time, whatever it might be.

The choice of gust sensor between a gust vane or an accelerometer was settled on grounds of robustness and general engineering and an accelerometer was chosen (though both could be made to do the job).

The lack of a definitive specification for real atmospheric disturbances was of concern and search was made to find records of turbulence containing samples of high intensity such as might give rise to limit loads on the wing. Such data were available as CAADRAP records and, with the analysis that was done on them, are discussed in a later section.

A system designed to alleviate up gusts can use aileron and spoiler. Down gusts can be alleviated by the aileron only (unless spoilers are fitted to the under surface). But civil transport underwing surfaces are usually designed by fatigue considerations of the tension loads resulting from up bending. To save weight on the under surface by using a GLA system requires (inter alia) a reduction in the fatigue loading. Some 60 - 70% of the fatigue loading is the ground-to-air cycle which a GLA system would not alter, the remainder could be alleviated. To do this a GLA system would have to operate at all G levels and this is a possibility. However, in doing so, the GLA system receives a heavy duty which reflects upon its robustness, reliability and maintainance. The other option, of introducing a threshold below which the system does not operate, does not reduce the fatigue spectrum but is kinder to the system itself.

The definition of a GLA system which emerged from these studies was one having a high response rate, 500°/sec. for spoilers and 250°/sec. for ailerons, driven by a single central accelerometer. As such, the system is not closed loop (in the sense of attempting to null an error) but open loop in the sense of attempting to follow the basic acceleration signal. A dead zone was introduced to avoid excessive wear from unnecessary usage, but this could not be set too high or too much time would be lost for the system to respond. Figure 4.

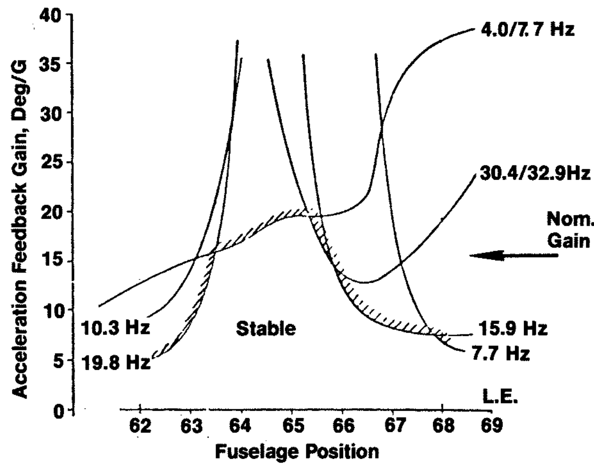


GLA SIGNAL

Fig. 4

A threshold of 0.3 G was chosen. The higher frequency component of the accelerometer would be deemed to be 'gusts' and a figure of 0.7 cps was chosen as the cut-in frequency. Great concern was felt with regard to the lags between force output and accelerometer input, which might exist in the system, of which the actuator was likely to be the most significant and the transport lag of the digital computation a close runner-up. To compensate, a phase advance filter was envisaged. This and predecessor systems were extensively analysed and in general with very satisfactory results, using a full dynamic model of a 'BAC 1-11 like' aircraft involving the rigid body degrees of freedom and 20 symmetric vibration modes.

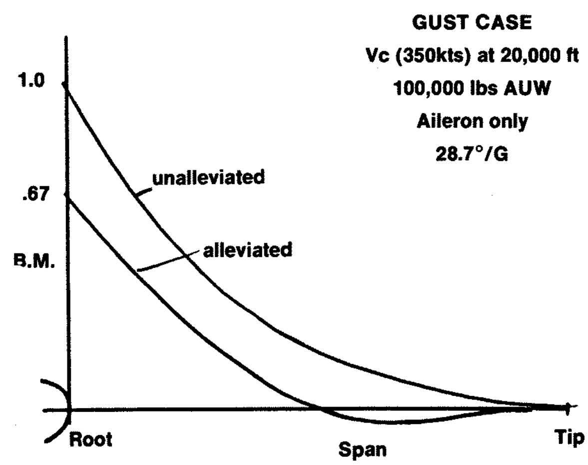
However a major difficulty, which was no surprise, emerged in that the aircraft with it's GLA system was flutter prone. A wide range of positions of accelerometer was tried. Eventually a position close to the CG on the centre line of the aircraft was deemed satisfactory using a linear dynamic model with aileron alone when aiming at a 50% reduction in incremental BM (1/3 off the total) from an isolated gust of design magnitude considered as independent of wave length (as in the then British Civil Airworthiness regulations). Figure 5 illustrates the kind of flutter instability boundaries obtained.



GAINS FOR INSTABLITY - ACCELEROMETER ON FORWARD FUSELAGE

Fig. 5

These results were of course very sensitive to the fuselage movement at the sensor in each of the (calculated) vibration modes and the repositioning of the accelerometer a few inches either way could make considerable difference. The BM with and without alleviation is illustrated in Figure 6.



DESIGN B.M.

Fig. 6

It is immediately apparent that the % reduction in BM varies greatly along the span and in particular the outer wing BM is in danger of exceeding the unalleviated BM when using an outboard control only.

This feature leads to the need to share the alleviation between several control surfaces - as would of course be plain from general considerations. Totally new aircraft designed from the outset with GLA should provide for several motivators, each provided with its own signal albeit taken from some single source.

A constant gain is desirable for simplicity and was shown to be satisfactory.

The design with a single accelerometer on the aircraft centre line denies any opportunity of sensing any antisymmetry in the gust input, which therefore produces a BM contribution which such a GLA system cannot alleviate. This is a contribution of about 3% of the unalleviated BM or about 5% of the alleviated BM.

A simpler version of such a system was also studied in which, if the accelerometer signal exceeded the threshold, the controls immediately go to full travel and then drift back according to a preset scheme. This has the disadvantage that if the gust changes sign immediately - as is likely - there will be increased load in the opposite direction. Such a system is useful, provided that the authority is limited to that consistent with the difference in wing strength in up and down bending and is generally of the "20% alleviation" class.

Finally these studies indicated a need to include hydraulic accumulators to ensure that the full (hydraulic) actuator rate was available in the event of a succession of large sharp gusts by ensuring an adequate supply of high pressure fluid.

A detailed design of this nature was made and implemented for a flight demonstration as described later.

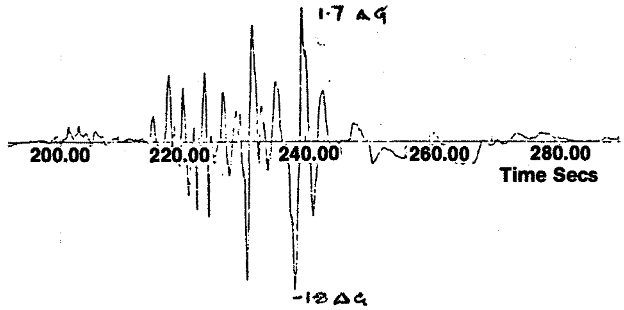
The Turbulence Description

A GLA system must be effective in encounters with real turbulence. Both the isolated gust and the continuous turbulence procedures are recipes. Much time history data of CG acceleration in response to turbulence exists in the open domain but is very largely of low intensity level.

Gusts which produce loads close to proof load, many think, arise from deterministic phenomena like mountain waves, jet streams and convective storms. This data is sparse. However, the CAADRAP data of the 70's is a source and is published. (Reference 2). It gives, inter alia, aircraft CG normal acceleration data, sampled at 8 samples per second, from a number of British Airways medium range aircraft where the peak incremental G was greater than 0.6.

British Airways have continued the programme with another called SESMA which extracts similar data but from a wider range of their fleet for incremental G greater than 0.5.

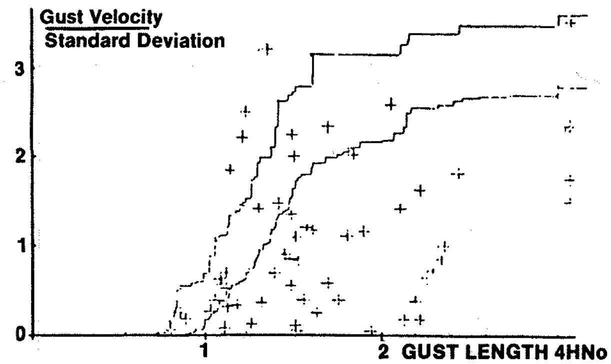
The CAADRAP data, typified by Event 1332, Figure 7 has been analysed by J. Taylor (Reference 3) under contract to BAe with a view to establishing a relationship between gust magnitude and gradient distance for the large gusts.



TURBULENCE SAMPLE

Fig. 7

The usefulness of incremental G as a measure of gust velocity was revalidated, but the 8 samples per second sampling rate was on the low side. His result is given in Figure 8.



Constant probablity lines for joint probability of peaks and gradient length.

Fig. 8

This work and others, (Reference 4) indicates strongly that for gust patches of proof load levels the large gusts have the longer wave lengths. If this conclusion is accepted, then the implications for gust analyses in general and GLA systems in particular are great, because it implies that it is the longer wave length gusts (c. 1000 ft) which produce the design loads. These are effectively the 'jet upsets' of the 60's, and could be alleviated using the elevator alone.

The Demonstrator Programme

Following the decision to mount a flight demonstration, the company BAC 1-11 (Figure 1) was modified to incorporate systems for

Relaxed Stability
Manoeuvre Load Alleviation
Gust Load Alleviation.

As a preliminary to the GLA testing a further test was mounted to ascertain the forces directly produced aerodynamically by a spoiler when moving rapidly, as it would be required to do as part of a GLA system. This test was called the Unit Spoiler Test (UST). Previously tests had been done at RAE but flight confirmation was desired. (Reference 5).

The plan, which was implemented, was to modify the aircraft in stages to test each item separately and then in pairs and finally with all three together. The UST was in fact done first.

The modifications made are not described in detail, being specific to type, but the salient features are outlined.

General

The three control laws were all implemented in-house digitally, using two identical computing systems each containing an LSI-11 processor. These two computing systems are referred to as CAS and LAS; the first being loaded with software for the Relaxed Stability (CAS) task; the second being loaded with software for both the MLA and GLA tasks.

The digital computing system and the hardware for the relaxed stability were rig-tested on rigs of the 'iron-bird' kind.

The objective was not to implement systems of certificatable engineering integrity, but to demonstrate the principles. A low integrity was acceptable since the flying would be short and the pilots would be skilled test pilots flying under BAe's flight testing control procedures.

Since the aircraft's wing strength - in the case of LAS - was not impaired (i.e. strength was not taken out) there was no concern for GLA/MLA. However, in the Relaxed Stability case the CG was planned to be taken up to and perhaps beyond the Manoeuvre Point and, even though the tail size was not to be changed, under certain malfunctions there was an element of hazard. Accordingly the single channel CAS system was provided with various extra elements of monitoring and protection which eventually approached the level of integrity which a multi-channel system would have given.

The Strain Gauge System & Calibration

The UST, MLA and GLA tests all had as their objective results in terms of wing Bending Moment Shear and Torque. Accordingly three stations (0.2, 0.5, 0.7 span) on the port wing were instrumentated appropriately.

Although desirable, the strain gauge system was not calibrated on the ground and resource was made to calibration in the air using:

Push/Pulls
Steady Turns
Flap Deployment
Inner/Outer Spoiler Deployment.

In the cases of deployment of the flaps and spoilers, the change in strain gauge readings contained significant contributions from the pitch change due to retrimming making interpretation difficult. The calibration data was used to assess the BM Shear and Torque of some desired unknown loading whose strain gauge readings had been measured. The procedure used was a least-mean-squares curve fit of the strain gauge readings by those from the calibration loads. The calibration loads were calculated from "office data".

Relaxed Stability

The elevator control system is rod operated to actuators in the tailplane on the top of the fin. A single 'series-actuator' was engineered into the circuit downstream of the feel unit which was fed with the CAS signal. Thus the elevators were driven by the combined inputs of the pilot and the CAS system.

A water tank system was installed in the fuselage which enabled the CG to be moved from 0.2 smc to 0.51 smc (normal range 0.2 smc to 0.42 smc) with facilities for rapid transfer between tanks and water dumping in emergency.

An activity meter was installed to indicate to the pilot what was actually happening to the elevator angles.

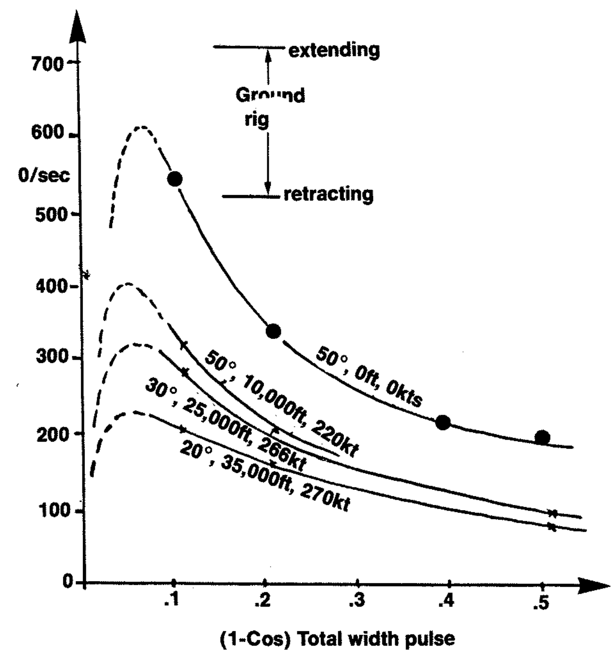
The basic control laws previously described were augmented with correction terms for roll, disconnect on the ground and tailplane position.

Digital monitoring by comparison of actual and predicted responses of the aircraft and separately the actuators, was made and in the event of disagreement an actuator washout filter was activated which disconnected the system and returned the elevator gently back to neutral by centering the series actuator. This worked well after a little adjustment of discrimination levels. However under certain extreme conditions and with multiple failures there was predicted to be an unacceptable risk in the event of an undetected hardover. To guard against this, another accelerometer was installed which would centre the actuator on exceeding a preset G threshold. To date this final protection has not been called upon to function. In the event of these trips working, the pilot would be connected to the controls in the normal manner.

Load Alleviation

The outer spoilers were used to demonstrate GLA, since they were powered (dispensing with their normal function as speed brakes). The ailerons were used for MLA. The level of alleviation that could be achieved with the chosen maximum control angles of 50° for the spoiler and 20° for the aileron was of the order of 15% (at the root) but the level was immaterial since the demonstration was of the principles only.

For the GLA system the existing spoiler actuators were modified by Dowty Boulton Paul, the hydraulic return lines were increased in size, an accumulator was added and an ABEX 415 control valve was installed. The rates that were achieved on ground test for excursions up to 50° of spoiler angle are shown in Figure 9. The actuator itself with its feedback system was completely stable.

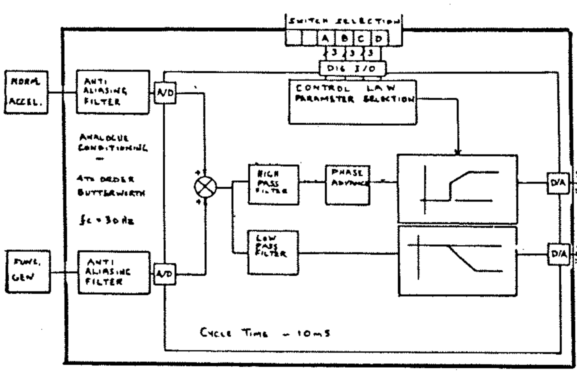


ACHIEVED SPOILER ACTUATOR RATES

Fig. 9

For the MLA system an electric series actuator from Lucas Aerospace was installed in the tab link thereby effectively 'powering' the aileron at low rates quite sufficient for MLA. Some concern was felt that in driving the aileron via the tab an unacceptable lag might occur, but this proved not to be the case. On the BAC 1-11 an anti-upfloat cable circuit is standard and inhibits symmetric motion of the ailerons. For the MLA testing this circuit was removed which led to some restriction of the flight envelope; in particular flight close to the stall was denied.

Both MLA and GLA were driven by signals from a central accelerometer processed by laws in the LAS computer, Figure 10.



LAS CONTROL LAW BLOCK DIAGRAM

Fig. 10

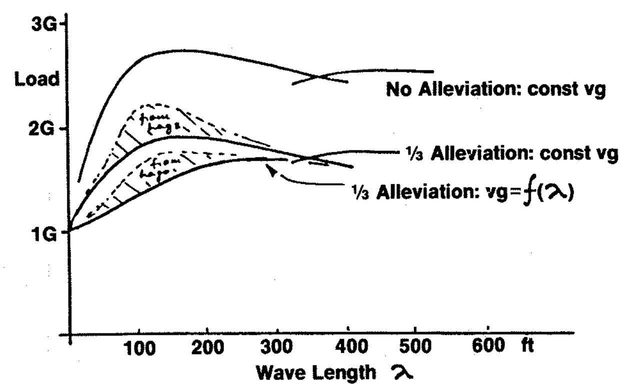
For the Unit Spoiler Test a Signal Generator (SG) was built which supplied a signal fed directly on to the Abex valve.

The SG produced a ramp signal of rise/fall time T_1 secs. and a 'plateau' time of T_2 secs. with a selectable 'plateau' amplitude.

This signal was described as a pulse of time $2T_1 + T_2$ within the range 0.1 to 4.0 secs. For a gust of 1/2 wave length of 150 ft and for a typical cruise speed of 800 f/s TRUE the gust pulse width is .38 seconds and this is indicative of the region of greatest interest under current isolated gust regulations.

For the GLA test there was the fundamental difficulty that it was most unlikely that real turbulence or gusts of large magnitude would be encountered in the flight programme envisaged. Therefore a Function Generator (FG) was built which supposedly simulated the acceleration that would result from the aircraft's encountering a 1-COS gust of selectable pulse width and magnitude. CAADRAP Event 1332 speeded up by x 1, x 2 and x 4 could also be selected. This signal was introduced just downstream of the accelerometer as though the accelerometer had produced it. In fact the signal from the FG was the 1-COS or EVENT 1332 shape itself whereas it should ideally have been the time history of the acceleration response to gusts of these shapes. Using a curve fitting process the gust shape which would have caused the FG acceleration outputs was calculated for subsequent use in the analysis of the results.

For the GLA the philosophy was therefore to stimulate the aircraft using the FG, measure the response (G, BM, Shear, Torque), calculate the response that would have occurred from the gust input assuming the GLA system to be not operating, add the two together and compare with the latter. In this process it is particularly important to pay attention to any time lags. Figure 11.



EFFECT ON ALLEVIATED LOADS OF LAGS

Fig. 11

Results from the Demonstration

Some 70 hours of flying in total were completed, the latest flight being in February of 1986. Not all the results are available. Some more flying is planned.

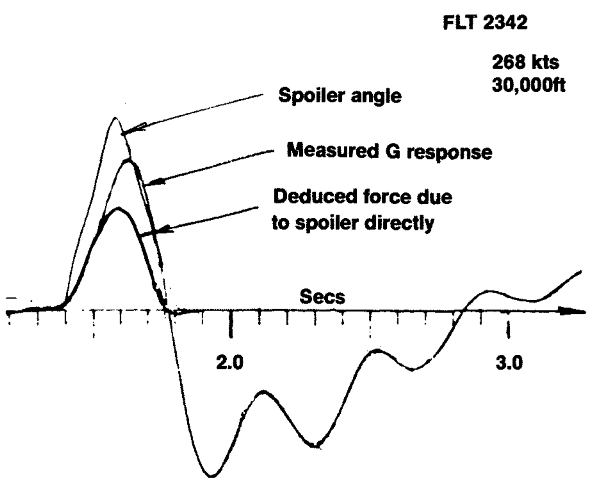
In general all the systems worked well and performed as expected.

Relaxed Stability

Altogether 14 flights were flown covering a CG range from 0.2 smc to 0.5 smc, the latter being effectively the manoeuvre point. The aircraft was flown both with and without CAS operating. The handling qualities were generally liked and pilots very soon adjusted to what is in fact a very different control system. The performance was just as good over the whole speed range tested and with flaps extended. The absence of a stick force per G gradient which CAS produces was very soon appreciated and liked.

The Unit Spoiler Test Results

Tests were made at Mach numbers .48, .64, .725 and .78 for a range of pulse widths from 0.1 to 4 secs. A typical result is shown in Figure 12 for aircraft G - strain gauge results are similar.

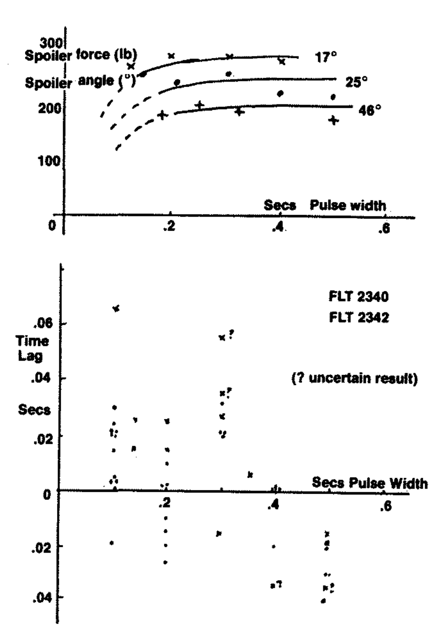


UNIT SPOILER TEST: .4 SEC SPOILER PULSE WIDTH

Fig. 12

It can be seen that the record is made up of response directly from the spoiler, rigid aircraft pitch/heave and aircraft vibration at 2.2 cycles. By computational means these last two contaminants can be removed with reasonable confidence to expose the desired force-time history caused by the spoiler directly which is also shown in the Figure. Of special note is the time lag between the peak spoiler angle and deduced force but the accuracy is poor.

Altogether several hundred pulses are available and not all have yet been analysed. Figure 13 illustrates the kind of result that is emerging. A time lag of .02 seconds is significant if short sharp gusts as already discussed are to be considered.

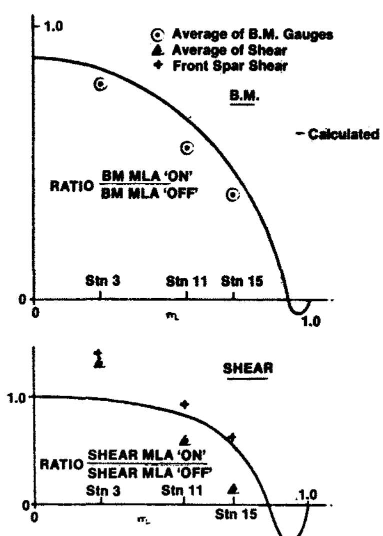


TIME LAG OF PEAK FORCE TO PEAK SPOILER ANGLE

Fig. 13

The MLA Test Results

As might be expected in what is essentially a simple system, the BM, Shear and Torque as a ratio MLA on/MLA off agrees fairly well with prediction, Figure 14. Results are available for Mach numbers .4, .53, .6 and .71.



M.L.A. TESTS

Comparison of SHEAR and B.M.

Fig. 14

The need for pitch compensation was confirmed by the pilots when flying with MLA ON. Operating CAS and MLA together proved very satisfactory.

The GLA Test Results

There was one snag, which was not unexpected. The GLA system was prone to limit cycle oscillation at frequencies between 10 and 20 cycles. In itself this was of minor concern in that, although the desired records would be contaminated by a small oscillation, the underlying record could be read. However, the detrimental effect on the serviceability (and even the life) of some of the components was judged excessive.

The reason for the oscillation was clear, since it also occurred on the ground, and was due to unbalance in the spoiler. The "cross inertia term" was inadvertently omitted from the predictions and so the oscillation did not show in their results. Partial mass balancing would have been a solution but was impracticable.

In the event the accelerometer was moved to a more aft position (decided by ground testing) and the flight envelope for GLA testing was cut back.

Results exist for pulse widths between 0.1 and 2 seconds for flight conditions up to 25,000 ft 275KTS EAS.

Very little analysis of the GLA results has yet been made and beyond saying that the system (as modified and restricted) worked satisfactorily, there is little yet to report.

The important question that the GLA testing is expected to answer is whether for large sharp 1-COS gusts (assuming they exist) there will or will not be disturbing response lags. If there are then the gain will have to be raised to compensate.

Combined Testing

Eight of the flights were made with system combinations. The handling qualities of the aircraft with MLA operating were much improved by also using CAS.

Otherwise no adverse interactions occurred.

Conclusions

Theoretical studies of Relaxed stability, Load Alleviation have been made and the principles tested in a BAe 1-11 Deomonstrator aircraft.

The Relaxed Stability CAS laws worked very well and pilots liked the system which was tested with CG up to the manoeuvre point.

The MLA system behaved satisfactorily as expected.

The UST showed that a spoiler was useful as a motivator for GLA but some lags possibly exist.

The GLA system exhibited limit cycle oscillation requiriing system modification. Results obtained are satisfactory but the assessment is incomplete.

References

1 Active Controls for Civil Aircraft. H P Y Hitch. Royal Aeronauical Society, Aeronautical Journal October 1979.

2 A presentation of measured aircraft responses in turbulence during civil operations. S D Ellis RAE TR 78113.

3 Comparison of a turbulence model from operational CG records with measured vertical gust velocity on research flights. J Taylor WBR/JT/7 (unpublished).

4 Summary of information relating to Gust Loads on airplanes. P Donely NACA TN 1976.

5 The dynamic characteristics of rapidly moving spoilers at subsonic and transonic speeds. D G Mabey et al RAE TR 82109.