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Avro Aircraft Limited

INTER-DEPARTMENTAL MEMORANDUM

Date	6th, May 1958	Reference Number:	8792/02E/J
To	Mr. C. V. Lindow		
From	S. Kwiatkowski		
Subject	MANOEUVRE LIMITING DEVICES IN THE ARROW DAMPER		

The following devices limiting the pilot or automatic commands and/or protecting against damper failures resulting in manoeuvres causing large structural loads will be in operation with fully developed Arrow Damper:

1. Command limiter - pitch
2. "G" limiter (pitch)
3. Command limiter - roll
4. Roll rate limiter
5. Aileron limiter (transverse acceleration)
6. Transverse acceleration monitor
7. Rudder hinge moment limiter
8. Mode transfer switch (sideslip)

In this note operation and the basic principle of each of these devices is briefly discussed and types of failure against which protection is provided are indicated. Some of the above devices are not yet fully developed since additional information from flight test is required and therefore a large portion of numerical data necessary for full description of their operation is not available. Particularly full information is not yet available on amount of protection offered in areas of the flight envelope where combined effects of aerodynamic non-linearities, high effective airspeeds, aeroelasticity, aerodynamic cross-coupling, reduction in control effectiveness, control hinge moment limitations etc. may tend to produce critical loads in certain manoeuvres. However all these effects were considered in the design of the limiters and satisfactory protection will be achieved when all the necessary information is available. All the limiters are designed to operate in the normal damper mode only with exception of the rudder hinge moment limiter which is available in both normal and emergency control modes.

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1. Command Limiter - pitch

Limits pilot's or any of the automatic commands to a fixed value of normal acceleration at approx. 4 to 5 positive "g's" (value not yet selected) and to negative one "g". Both will be constants throughout the flight envelope substantially below the structural limit and held to a close tolerance. Possible overshoots will be small because the damper will control them to approx. 10% in the worst case. The command limit is achieved by limiting the voltage output of the stick force transducer.

Provides protection against any failure forward of the stick resulting in hard-over command e.g. in the autopilot, fire control etc.

The command limiter can be overpowered intentionally by the pilot by applying stick force of approx. 75 - 90 lb which is substantially higher than stick force for maximum command (approx. 25 - 30 lb).

2. "G" Limiter

The "g" limiter protects the aircraft against malfunctions of the damper such as:

runaway parallel servo
runaway differential servo
loss of pitch rate

Partial protection is also offered for a simultaneous ramp inputs of both parallel and differential servos.

The limits of protection are discussed in M-H Document R-ED-9240 MH 64 G Limiter status dated January 17th, 1958 -
The limit function is mechanised as follows:

$$\left(n_{z_{CG}} + \frac{162}{g}\dot{q}\right) \cdot \frac{1 + .02S}{1 + .1S} + 15.75\ \delta_p \frac{.5s}{1 + .5s}$$

$$+ \ 12.5\ \delta_D \frac{2S}{1 + 2S}$$

where $n_{z_{CG}}$ - normal acceleration at c.g.

$\dot{q}$ - pitching acceleration

δ_P - parallel servo deflection

δ_D - differential servo deflection

The first two items are obtained by combining outputs of two normal accelerometers suitably spaced along the longitudinal axis. The remaining two inputs are virtually differentiated by electrical

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2. "G" Limiter (Continued)

networks such that the limit function contains in addition to accelerations the directions and rates of servo motions. Should the total exceed a predetermined value the pitch axis will be disengaged by effectively disconnecting the hydraulics in the servos. It can be seen from the limit function that the actual value of "g" at which the disengagement occurs will vary with the flight conditions, rates of application of command and type of failure. However, the resulting overshoot will be kept inside the structural limits of the aircraft, since this was the basic aim in the design of the limiter. On the other hand a so called "nuisance disengagement" may occur in a manoeuvre inside the flight envelope at a few specific flight conditions. Obviously the number of "nuisance disengagement" is kept to the minimum but it is not feasible to eliminate them completely in order not to jeopardize the protection at other conditions.

If the "g" limiter action was caused by intentional pull on the stick, at the disengagement of the pitch axis of the damper there will practically be no change in the stick force, therefore, higher load factors will not be pulled inadvertently. If the limiter disengages with no force on the stick (e.g. in the automatic mode) the aircraft will immediately be returned to within $\pm \frac{1}{2}$ g of level flight by the centering action of the servos.

3. Command Limiter - roll

Limits pilot's or any of the automatic commands to 120°/sec. of roll rate or the maximum roll rate available aerodynamically if the latter is less than 120°/sec.

The command limit is achieved by limiting the voltage output of the stick force transducer similar to pitch command limiter.

Can be intentionally over-powered by applying approx. 40-50 lb. at the stick. Protects against any malfunction forward of the stick resulting in hardover signal.

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4. Roll Rate Limiter

The action of the roll rate limiter is based on a wing tip accelerometer set to disengage the roll axis at approx. 160°/sec. of roll rate. Therefore, it protects against any malfunction of the damper resulting in a hardover parallel or differential servo signal.

At the instant of disengagement there generally will be a change in stick force, but in the majority of cases the emergency mode stick force will be higher than in normal mode.

5. Aileron limiter (transverse acceleration)

This limiter protects the fin in rolling manoeuvres resulting in high fin loads. The action of this limiter is based on a transverse accelerometer located 30 ft. forward from aircraft c.g.

In the normal mode the ratio of aileron stick force to roll rate is a constant throughout the flight envelope approx. 20 lb. of stick force per 120°/sec. of roll rate. This ratio is monitored by the aileron limiter in such a manner that whenever a transverse acceleration of .6 "g" is reached the stick force transducer output becomes zero e.g. no roll rate can be commanded. The rate of increase of aileron stick force per unit of roll rate is linear with transverse acceleration, with a shallow slope applying up to .2g and steeper slope up to .6g, the latter corresponding approx. to 50% of fin limit load. This limiter is independent of other damper actions and will limit the aileron output no matter what has caused the increase in transverse acceleration.

The action of this limiter is particularly important in prolonged rolling manoeuvres e.g. in excess of 180° of bank angle or at high roll rates in rolling pull-outs where cross -coupling effects are particularly significant and generally in any rolling manoeuvre causing saturation of the rudder servo to deflection or hinge moment limit.

6. Rudder Monitor

Rudder monitor provides protection against any malfunction of yaw axis, resulting in hardover rudder signal automatically in level flight. The normal damper is disengaged and emergency damper engaged when transverse acceleration reaches .4g as measured 40 feet ahead of c.g.

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6. Rudder Monitor (Continued)

The limit function of the accelerometer is as follows

$$\ddot{y}_{40} = \ddot{y}_{C.G.} - 40\,(pq + \dot{r})$$

It can be seen that in manoeuvering some anticipation is obtained due to yaw acceleration and roll rate and pitch rate product. The actual fin load at disengagement will depend on flight condition and type of manoeuvre. The limiter was designed to disengage at approx. 50% of fin load but in a few conditions at high E.A.S. (above 650 knots) this is exceeded and switching does not occur until 80% of fin load is reached. The limiter is designed to cater for max. rudder rate of 50°/sec. This device is not fully developed yet and some uncertainty exists about the amount of protection provided when failures occur during extreme manoeuvres, e.g. a rolling pull-out.

It was not feasible to design a relatively simple emergency damper which would provide coverage of all possible manoeuvres involving sideslip. Therefore if due to malfunction of the normal damper, the rudder monitor engages the emergency damper during extreme manoeuvre fin limit loads may be exceeded unless a prompt pilot's action will minimise occuring sideslip. These conditions occur mostly at high E.A.S. and in extreme manoeuvres. At the present time not enough information is available to define in detail extent of the protection provided for manoeuvres involving high roll rates and normal accelerations. These new problems involving cross-coupling effects are common to most aeroplanes operating in the flight envelopes similar to that of the Arrow and further development time will be needed to obtain sufficient information permitting redesign or modifications of the rudder monitor to obtain a maximum possible protection.

7. Hinge moment limiter

A hinge moment limiter combined with pilot's trim and feel unit in the rudder performs the following functions:

1. Provides variable feel with speed and altitude.
2. Limits the pilot's input into the rudder to values such that 150 lb of pedal force will not exceed the fin limit load, with dampers off.
3. Ascertains sufficient servo authority independent of the pilot particularly in areas where total rudder deflection is heavily restricted by the available hinge moment.

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The hinge moment limiter consists of variable linkage, and springs and trim motors, common to any artificial feel and trim unit. The variable linkage is driven by an electric actuator receiving signals from the dynamic pressure sensor.

In normal damper gear-up mode the use of rudder bar is necessary only to trim out an engine out condition or any other aerodynamic assymetry, otherwise the aeroplane is basically a two-control aircraft. In gear-down mode rudder is used in a conventional manner for landing and take-off. It may be used as an alternative way of correcting minor damper malfunctions. In the emergency mode of control rudder may be used to help co-ordinate manoeuvres which are not adequately co-ordinated by the damper.

The failure of hinge moment limiter may cause inadvertent too large pilot's corrections resulting in high fin loads at high speeds.

8. Mode Transfer Switch (sideslip)

This switch operated by the relative wind sensor switches over normal damper into emergency mode whenever a sideslip angle of 10° is reached. This is applicable only to low speed range e.g. where the 10° of sideslip produce less than 50% of the fin limit load.

Protects against hardover type of malfunctions in the low speed region.

<u>CONCLUSION</u>

It can be seen from the above description that with normal damper in flightworthy condition the aircraft manoeuvres are positively limited to:

1. Straight pull-ups to 4 - 5 positive "g's" or approx. 80% of limit load depending on aircraft weight and c.g. position. In the operational range e.g. above 40000 ft. at any speed the maximum positive "g's" are limited by elevator deflection or hinge moment.

2. Straight push-downs to one absolute "g" negative which is well inside the structural envelope.

3. Maximum roll rate to 120°/sec. or approx. 35% of limit load.

4. Rolling pull-out to roll rates not exceeding 120°/sec. or approx. 50% of fin limit load, whichever occurs first.

5. Fin load to approx. 50% of limit load in any manoeuvre.

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CONCLUSION (Continued)

6. "Nuisance" disengagements of any axis will produce loads generally smaller than quoted above.

7. With the hinge moment limiter operating application of 150 lb force to the rudder bar will produce only small fin loads.

8. Overshoots in pitch and roll axes for abrupt applications of controls will be much smaller than in unaugmented air-frame. Representative magnitude of overshoots in both axes is 10%.

The above loads can be exceeded only by intentional overpowering of the parallel servos requiring very large control forces or due to malfunctions of the damper system. The emergency mode of control will be limited (by pilot's instructions) to manoeuvres and speeds fully covered by emergency damper.

Failures of the normal damper with limiting devices operating will result in loads inside the structural flight envelope with exception of failures occuring during extreme manoeuvres.

The policy of structural integrity testing should be reviewed bearing in mind the presence of limiters described above. Furthermore it has not been established yet that loads in excess of normal command limits can be tested in a manner offering a reasonable amount of safety from controllability point of view.

SK/g

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