BAC 1-11 408EF, G-AVGP

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Aircraft Type and Registration:	BAC 1-11 408EF, G-AVGP
No & Type of Engines:	2 Rolls-Royce Spey 511-14 turbofan engines
Year of Manufacture:	1967
Date & Time (UTC):	13 February 1996 at 2142 hrs
Location:	Aldergrove, Belfast
Type of Flight:	Public Transport
Persons on Board:	Crew - 5 - Passengers - 14
Injuries:	Crew - None - Passengers - None
Nature of Damage:	Flexible hydraulic brake hose ruptured
Commander's Licence:	Airline Transport Pilot's Licence
Commander's Age:	35 years
Commander's Flying Experience:	4,270 hours (of which 2,940 were on type)
	Last 90 days - 98 hours
	Last 28 days - 39 hours
Information Source:	AAIB Field Investigation

History of the flight

The initial part of the flight proceeded without incident butupon reaching a position approximately 30 miles southeastof the Isle of Man VOR, the crew noted that the No 2 hydraulicsystem contents had fallen to just inside the red sector of theassociated indicator.

The QRH drill for low hydraulic contents was carried out and aPAN call made to Scottish Area Control Centre. In view of therunway length available at Aldergrove (2,777 metres), the planneddestination, a decision was made to continue the flight and asuccessful approach and landing was carried out using 45°flap. After touchdown, normal reverse thrust was used followedby minimal application of the foot brakes; however, as the aircraftdecelerated through about 30 kt the foot brakes failed completelyand the aircraft was brought to rest using the parking brake.

During the rollout the airport fire service, which had positionedbehind the aircraft, reported that smoke could be seen comingfrom the aircraft and the commander therefore instructed the

cabincrew to evacuate the passengers from the forward door using theairstairs, as soon as the aircraft stopped on the runway. However,the loss of hydraulic pressure prevented the L1 airstairs frombeing extended under power and a decision was taken to deploythe associated emergency slide. The evacuation was carried outsuccessfully and there were no injuries.

Subsequent examination of the aircraft by maintenance personnelidentified a leak from a flexible hydraulic pipe supplying theoutboard wheel brake on the left main landing gear. The pipewas replaced with a serviceable item, and after replenishmentand bleeding of the hydraulic system, the aircraft was returnedto service.

The failed pipe was subsequently examined by AAIB on 15 March1996, after the aircraft had returned to Birmingham. G-AVGP,and three other BAC 1-11 aircraft from the operator's fleet whichhappened to be parked on the stands at Birmingham, were also inspectedwith a view to obtaining a better understanding of the failureon G-AVGP, and to establish whether other aircraft were similarlyaffected.

Flexible pipe arrangement

Figure 1a shows the locations of the relevant pipes. There arethree flexible brake pipes on each landing gear, the outer pairproviding individual *primary* supplies to each brake unit,and the centre pipe providing a common *stand-by* supply. The detailed construction of the pipes can differ, but the pipein question comprised a PTFE pressure tube inside an outer structuralsheath of braided steel, which in turn was encased in a thin plasticouter sleeve.

At their upper ends, all three brake pipes connect to an articulatedwalking joint assembly, see Figure 1b. At their lower ends,the *primary* pipes pass through hard nylon support bushesfixed to the lower part of the landing gear leg (the manifoldbracket assembly), approximately 150 mm (6 inches) abovethe end connections to their respective shuttle valves, as shownin Figure 1c. The bottom end of the stand-by pipe connects toa manifold assembly, also fixed to the lower section of the leg,which supplies the opposite ends of each shuttle valve via shortsections of rigid pipe.

Pipe failure details

The pipe on G-AVGP, bearing the part number EN43-A435, had failedat the point where it passed through the (hard nylon) lower supportbush, at approximately the position shown in Figure 1c. Deterioration and breakdown of the plastic sleevings at this locationhad allowed abrasion of the steel braid, leading to failure ofnumerous strands of the braid and a pressure-induced rupture ofthe plastic inner tube. Figure 3a shows a close-up view of thefailure region.

The diagram at Figure 2 shows the position of the failure on thepipe. In addition to the abrasion and chaffing on the lower sectionof the pipe which had led to the failure, three additional areasof chaffing damage were evident: two on the upper regions of thepipe and a third slightly below the rupture location at the bottomof the pipe; these are also shown in Figure 2. The abrasion damagein the region 200 mm to 210 mm (7.9 inches to 8.3 inches) wasconsistent with fretting contact between the curved part of thepipe and the scissor-link element of the walking joint assembly. The damage region between 365 mm and 390 mm (14.4 inches and15.4 inches) was positioned well away from any part of the walkingjoint, and had evidently been caused by rubbing contact againstthe inside face of the outboard mainwheel tyre.

Other flexible brake pipes on G-AVGP

The other three *primary* brake pipes on G-AVGP exhibitedsimilar chaffing damage in the area where they passed throughthe lower support bushes, and the sharp ends of broken strandsof braid could be felt adjoining the edges of the bushes on twoof these pipes.

It was noted that the replacement pipe fitted to G-AVGP followingthe incident was of a larger diameter than either the original(failed) pipe or the adjoining pipe on the left gear. It wasalso of markedly different construction, with a thick textileouter protective sheath in place of the thin plastic sheath. The corresponding pipes on the right landing gear were of yetdifferent construction, having the larger external diameter ofthe replacement pipe, but with an outer protective sheath of braidedsteel. It was noted that the larger diameter variants of thepipes were a relatively snug fit in the lower support bushes (thechaffing location), whereas the smaller diameter pipes were avery loose fit, to the extent that they were free to 'rattle around'in the bush.

Service bulletin PM 5633

The flexible pipes originally fitted to BAC 1-11 aircraft wereassembled from 12.1 mm (0.475 inches) outside diameter (OD) flexiblehose having a rubber core. In 1979, Service Bulletin PM 5633introduced a modification to replace rubber-cored flexible hydraulichoses with PTFE-cored hoses. In the case of the main landinggear walking joint hoses, the Service Bulletin specified replacementof the main brake hoses with a *post-mod* standard pipe carryingthe British Aerospace part number EN43-A435; new post-mod standbybrake hose and upper clamp blocks were also specified. The 'description'part of the Service Bulletin states,

"To cater for a reduction in outsidediameter on new nosewheel steering feed hoses and an increasedoutside diameter on new M.L.G walking joint hoses, new clampblocks are introduced."

The nominal diameter of the post-mod pipes was 12.7 mm (0.500inches). On the issue of interchangeability, the Service Bulletinstates that,

".....the nose undercarriage steeringfeed and main undercarriage walking joint hoses must be replacedas complete hose assemblies, as new clamp blocks are requiredto cater for revised outside diameter of post-mod hoses. Preand post-mod affected hoses should not therefore be mixed."

It is notable that whilst the Service Bulletin addresses the issueof replacement clamp blocks at the top ends of the pipes, in orderto accommodate the increase in OD from 12.1 mm to 12.7 mm (0.475 inchesto 0.500 inches), no mention is made of how this diameter differenceis accommodated at the lower support bushes.

The part number marked on the pipe which had failed on G-AVGPwas EN43-A435, the post-mod part number. However, contrary tothe statement made in the Service Bulletin that the post-mod pipeswere of increased diameter, the failed pipe utilised a PTFE typepressure hose of smaller outside diameter, 9.8 mm (0.385 inches)OD, and witness marks at the top end of the pipe suggested thatthe upper clamp block had been sized to match this reduced diameter.

Pipe manufacture

The BAe assembly drawing for the post-mod pipes comprises, ineffect, a table of part numbers, dimensions, and other data whichdefine a range of the flexible pipes used on BAC 1-11 series aircraft,including the brake pipes in question. For each of the pipescovered by the drawing, the table specifies flexible hose typesfrom two alternative manufacturers, Aeroquip and Fliteline, byreference to those manufacturers' own part numbers. The drawingmakes no explicit reference to

hose-stock diameter, but in thecase of main landing gear walking joint pipes (and nosewheel steeringfeed pipes), the drawing states that where these are assembledusing Aeroquip hoses, two diameter-increasing external sleevesmust also be fitted at specified positions; one near the top endof the pipe and the other near the bottom. The additional sleevesare evidently not required in the case of pipes assembled fromFliteline hoses.

BAe manufacturing procedures require that the various sub-assemblypart numbers are engraved onto a small metal collar, which remainspermanently on the pipe. The assembly number EN43-A435, however,is engraved onto a temporary metal tag which is attached to thepipe temporarily with locking wire, and is required to be removedprior to installation on an aircraft. Consequently the primarymeans of identifying the pipe is lost once it has been installed.

Survey of in-service pipes

Pipe condition on other BAC 1-11 aircraft from the operator'sfleet

The flexible brake pipes fitted to the three other BAC 1-11 aircraftfrom the operator's fleet examined at Birmingham were found tobe in a broadly similar condition to those on G-AVGP, with damagedprotective sheathing and worn braiding where they passed throughthe lower support bushes. In several cases, broken strands ofbraid were also evident.

In the light of these findings, the CAA area office with responsibilityfor Birmingham was informed. In addition, the operator independentlyundertook to inspect, and where necessary to replace, all of thewalking joint flexible pipes on its fleet of 1-11 aircraft. Twentythree of the pipes thus removed were later sent to AAIB to assistwith the investigation. Examination of these pipes revealed thefollowing:-

<u>Small diameter types</u>

Thirteen of the pipes were of the smaller diameter type (9.8 mm(0.385 inches) OD, similar to the failed pipe), of which: 9 hadplastic identification tags bearing the (post-mod) EN43-A435 partnumber; 1 had a plastic tag bearing the part number EN63-A115(a BAe sub-assembly part number for the hose) and 1 had a metaltag bearing this same EN63-A115 part number; 2 had metal tagswith only partially legible part numbers; and 1 had no identificationtag of any kind. The thin plastic covering had deteriorated andbroken up over the lower part of the majority of these pipes.

The diameter-increasing protective sleeves, which should havebeen fitted to both the upper and lower ends of the (small diameter)pipes, were not present in the region of the pipe in contact withthe lower support bushes on 11 out of the 13, but sleeves werepresent at the extreme bottom ends of these pipes, abutting thelower end-fittings. On almost all of these 11 pipes, the thinplastic sheaths in the region where the pipe passes through thelower support bushes was damaged or missing, and abrasion damagewas evident on the steel structural braid; in many cases withbroken strands (Figure 3b shows a typical example). The 2 remainingpipes had a pair of diameter-increasing sleeves fitted at theirlower ends: the first abutting the pipe end-fitting, and the secondabutting the first. The lower regions of these pipes were innoticeably better condition than the others, and the structuralbraid was undamaged; however, the higher of the two sleeves hadin each case migrated down the pipe, puckering the sleeve 'concertina'fashion, with the result that the sleeve had only partially engagedin the support bush.

Single diameter-increasing sleeves were fitted to the upper partsof 7 of the pipes, but in most cases these were positioned toofar down the pipe to engage the clamps; typically 45 mm to 50mm (1.8 inches to 2.0 inches) below the upper clamp block,with the result that the clamps gripped the hose directly. Hadthe *correct* (post-mod) clamp blocks been used with thesepipes, as required by the Service Bulletin, they would have beensized to clamp 12.7 mm (0.500 inches) OD pipes, and thereforetoo large to grip the 9.8 mm (0.385 inches) OD hose properly. In most cases, however, witness marks on the pipes suggestedthat the clamping pressure had actually been correct implyingthat, contrary to the BAe Service Bulletin instructions, clampshad either been modified, or made specially, to accommodate thesmaller pipe diameter arising from incorrectly positioned sleeves.

The remaining two pipes had a pair of diameter-increasing sleevesfitted at their upper ends, one immediately abutting the end-fittingand a second abutting the first; these were the same 2 pipes whichhad the pair of sleeves fitted at their lower ends.

Large diameter types

Ten of the pipes were of larger diameter (typically 0.450 inches- 0.500 inches OD), with teflon or PTFE cores. Eight of thepipes had two layers of steel braid sheathing, of which 3 exhibitedworn outer braids and/or broken strands (Figure 3c shows a typicalexample). The remaining 2 pipes had a single sheath of braidedsteel in addition to a protective sleeve of tough, woven, textile.

Of the 8 pipes with the double steel braid, 4 had plastic identificationcollars bearing the part number AQ43A211 (the BAe assembly partnumber for the original standard of pre-mod pipe), 2 had plasticcollars bearing the part number EN63-A115 (a BAe sub-assemblypart number), and 2 had no identification markings of any kind. The 2 pipes with the textile outer sheath were fitted with steelpart number collars bearing identification numbers which included107066 (a Fliteline part number), and EN63-A115 (BAe sub-assemblypart number).

Pipe condition on BAC 1-11 aircraft from other fleets

In order to assess whether the abrasion problems encountered onthe operator's fleet were more widespread, the type and conditionof the walking joint flexible pipes were inspected on 5 in-serviceBAC 1-11 aircraft from another civil operator's fleet, and oneaircraft operated by the Ministry of Defence. It was found thatthe flexible pipes on these aircraft were mainly of the smallerdiameter type, many of which had damaged and missing sectionsof plastic sleeving and outer sheathing at the lower ends of thepipe, leaving the steel braid exposed and in loose chaffing contactwith the bores of the support bushes. Figure 4 shows a typical example.

The diameter-increasing sleeves at the upper ends of the smallerdiameter pipes had mostly been fitted below the actual clamp position(as noted previously). It was also noted that in several instances,the pipe cut-outs in the two halves of a given clamp block appearednot to match one another, suggesting that clamps of differenttypes may have been mixed.

Component origin

Is was not possible to determine with certainty the origin ofany of the pipes examined during the course of this investigation.

To assist with identification, a sample pipe manufactured fromthe smaller diameter Aeroquip type hose-stock was supplied byBAe to serve as an exemplar, for comparison purposes. This pipehad a pair of diameter-increasing sleeves fitted at both the topand bottom ends of the pipe: in each case, one abutting the end-fittingand a second abutting the first. It is understood that this pipewas from a batch supplied originally to BAe by the hose manufacturerwith the sleeves positioned incorrectly: effectively, with thetop and bottom sleeve positions reversed; the top sleeve beingtoo far from the end-fitting to engage the upper clamp block andthe bottom sleeve abutting the end-fitting, below the positionof the lower support bush. (In this regard the exemplar pipe,as supplied to BAe originally, was comparable to the majorityof the small diameter pipes surveyed, as commented upon previously.) Upon receipt, BAe inspectors found the error and the pipes werereturned to the hose manufacturer. Rather than attempt to removethe misplaced sleeves, with the attendant risk of causing damage,an agreement was reached with BAe that the problem could be remediedby the installation of a correctly positioned second sleeve ateach end of the pipe, leaving the originally fitted sleeves stillin place. The *rectified* batch was subsequently acceptedby BAe and entered the spares supply chain.

Comparison between the exemplar pipe and the pipes surveyed byAAIB suggested that those fitted with plastic identification collars(the majority) probably had not been sourced from BAe. However,three of the hoses did have metal identification collars bearingthe BAe EN63-A115 sub-assembly number together with several ofthe hose manufacturer's own part numbers. These metal collars,and the character of the markings on them, appeared visually identicalto the exemplar, suggesting that these pipes had been suppliedby BAe. Of these:-

two had a pair of diameter increasing sleeves installed at eachend, suggesting these had been part of the batch on which thesupplier had originally mispositioned the sleeves.

one pipe had both sleeves positioned too far down the pipe,*ie* the upper and lower sleeve positions reversed, comparableto the majority of the non-BAe supplied pipes and to the exemplarpipe as supplied originally to BAe.

Part numbering, identification, and conformity issues

Part numbering

No good reason was evident for BAe's practice of putting the assemblynumber on a separate *temporary* steel tag which must thenbe removed prior to installation, rather than adding the assemblynumber to the existing metal collar which records the other identificationnumbers, or to an additional *permanent* collar. This practicedeprives operators and maintenance organisations of a ready meansof checking that installed pipes are of the correct type; it certainlyled to unnecessary confusion during the course of this investigation,and was probably a factor in the confusion which evidently existsregarding the *correct* combination of pipe and clamp block.

Conformity

The high incidence of incorrectly positioned diameter-increasingsleeves appears to lie at the heart of wider problems of hoseand upper clamp block incompatibility, and excessive abrasionat the lower support bush, which are indicated in respect of manyin-service aircraft in the UK (and possibly elsewhere).

The BAe pipe assembly drawing was examined, and it was confirmedthat the drawing does take due account of the diameter differencesbetween Aeroquip (small diameter) and Fliteline (larger diameter)hoses by specifying diameter-increasing sleeves for Aeroquip-typehoses. The positions at which these sleeves should be fittedto the upper and lower ends of the pipe were also correctly specified. However, it was notable that whilst this information was strictlycorrect, the manner in which it was presented appeared open topossible misinterpretation, resulting in the positions of thetop and bottom sleeves being effectively reversed, and failingto match the positions of the hose support clamp and bush as aconsequence.

BAe do not supply pipe manufacturing drawings, except to theirown approved suppliers. However, it is understood that uncontrolledcopies of original drawings do exist outside BAe, and it is possiblethat these may have been used in the manufacture of some, if notall, of the non BAe supplied pipes examined. Alternatively,it is possible that a BAe supplied pipe with incorrectly positionedsleeves (*ie* with the top and bottom sleeve positionsreversed, as on the exemplar prior to rectification) may havebeen used as a pattern for the manufacture of replacement pipes. In either case, misinterpretation of the assembly drawing appearsto be the underlying reason for the preponderance of incorrectlypositioned sleeves on in-service pipes; it was almost certainlythe cause of the initial mispositioning in the batch of BAe pipesfrom which the exemplar was drawn.

The large number of the *in service* pipes examined whichdid not conform to the manufacturer's drawings suggests that *new*pipes presently in operator's stores holdings also may not conform. It also raises a similar question in connection with clamp blocksheld as part of existing spares holdings.

Pipe deterioration

By far the majority of the smaller diameter Aeroquip type hosessurveyed displayed extensive deterioration and breakup of boththe thin plastic protective sleeve and of the diameter increasingsleeves, particularly at their lower ends where they passed throughthe lower support bushes. In addition, a significant number ofthe diameter increasing sleeves at the bottom ends of these pipeshad migrated from their original positions, often in combinationwith *concertina* folding of the sleeves. Many of the pipesalso had worn or damaged steel braiding.

Although a visual inspection of the damaged plastic coveringsand sleeves did not suggest embrittlement of the type usuallyassociated with prolonged exposure to ultra violet, it was evidentthat in the case of the majority of pipes examined by AAIB, neitherthe *protective* nor the *diameter-increasing* sleeveson Aeroquip type pipes were providing the required protectionthroughout the in-service life of the pipes.

The prevalence of severe abrasion and multiple strand failureof the steel braiding of Aeroquip pipes suggests that operatorsmay not be fully aware that the steel braid on these pipes isstructural (unlike the earlier hoses, where the braid was primarilyintended to provide abrasion protection). Consequently, any deteriorationof the braid will give rise to a significant risk of hose rupture.

Implications of pipe failure

A ruptured brake hose will result in fluid loss whilst foot brakepressure is applied, leading potentially to exhaustion of allfluid and consequent loss of normal brake functions, includinganti-skid. A minimum of six full brake applications should bepossible thereafter using the hand brake, from pressure storedin the hand brake accumulator, but with no anti-skid functionavailable.

The primary supply to the foot brakes is taken from the No 2 hydraulicsystem. However, the flying control system is designed so thatloss of one hydraulic system should not affect adversely the handlingof the aircraft.

Safety action

On 15 February 1996, the CAA Regional Office Manager at East MidlandsAirport (the office with responsibility for Birmingham) was advisedby telephone of the high incidence of pipe abrasion and braidfailure found during the AAIB initial investigation.

Subsequent detailed investigation has brought to light a numberof problems affecting the walking joint flexible hose assembliesof a significant number of in-service aircraft on the UK register,and identified a range of apparent shortcomings. Specifically:-

Incorrect location of the diameter-increasing sleeves at bothends of Aeroquip type hoses appears widespread; specifically,upper sleeves are invariably positioned too far from the end-fitting,and the lower sleeves too near.

The adequacy of the plastic anti-abrasion sleeving on Aeroquiptype walking joint hoses is called into question.

The security of the plastic diameter-increasing sleeves fittedto the lower ends of Aeroquip type walking joint hoses appearsinadequate.

Severe chaffing and abrasion damage to the steel structuralbraid of Aeroquip type hoses, at the lower ends where they passthrough the (hard plastic) support bushes in the manifold bracket,appears widespread.

Upper clamp block incompatibilities appear to be prevalent;specifically, mismatching of pre and post-mod hose/clamp sets,and clamp blocks which not to confirm with British Aerospace specificationsfor either the pre or the post-mod standard of clamps.

The lack of any form of permanent assembly number marking onBAe supplied walking joint hoses, despite the presence of metalcollars bearing several sub-assembly numbers, compromises an operator'sability to positively identify the part number of pipes once theyhave been installed, adding to the potential for pipe and clampincompatibilities to arise.

The clarity of the Service Bulletin implementing the revisedhoses is less than ideal.

The British Aerospace hose assembly drawing appears open tomisinterpretation.

Safety Recommendations

As a result of the findings arising from this investigation, thefollowing Safety Recommendations have been made:

97-4: British Aerospace Airbus Ltd should issue a Service Newsletter,or comparable document, to promulgate to all operators of BAC1-11 aircraft information on the correct installation of landinggear walking joint flexible brake hoses and associated clamp blockassemblies, and to raise awareness of related compatibility issuesand correct maintenance procedures required.

96-48: British Aerospace Airbus Ltd, in conjunction with the CAA,should take action to require inspection of BAC 1-11 aircraftfor abrasion damage to the structural braiding of landing gearwalking joint flexible brake hoses, particularly in the hiddenregion within the lower support bush, and to require replacementof all damaged hoses found.

96-49: British Aerospace Airbus Ltd should critically review BAC1-11 Service Bulletin PM5633 and amend the contents as necessaryto ensure that these are correct and unambiguous.

96-50: British Aerospace Airbus Ltd should consider introducinga scheme for the permanent marking of BAC 1-11 landing gear walkingjoint brake hoses with the BAe assembly part number and take actionto ensure that all new post-modification hoses, presently in thesupply chain and held by operators as spares, have correctly positioneddiameter-increasing sleeves.