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AVRO AIRCRAFT LIMITED

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TECHNICAL DEPARTMENT (Aircraft)

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APPRAISAL OF THE EXISTING ARROW ESCAPE SYSTEM

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AVRO AIRCRAFT LIMITED
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REPORT NO.	70/SYSTEM 24/125
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1. INTRODUCTION

This report is written to present a brief evaluation of the suitability of the Arrow Aircraft escape system.

Results of tests and of theoretical studies are summarized and some recommendations are made, to facilitate the formulation of the engineering policy with regard to the system.

It is recommended that the development of the personal equipment, such as clothing, oxygen mask, and survival pack, be left in the hands of the RCAF.

As far as the remainder of the escape system is concerned, it is recommended to accept the Avro responsibility for its development.

In order to achieve a satisfactory system, several arrangements still have to be made.

Decisions on the following main issues are required:-

(1) To accept the introduction of the modification of the ejection control, to enable the pilot to eject the navigator.

(2) To reject the Martin-Baker Mk. C5 seat, in its present form, as not suitable for the Arrow 2 aircraft, and to accept the policy of improving this seat to make it suitable.

(3) To place an order with the Martin-Baker Co. for a development of the seat, to meet new Avro requirements (it would entail issuing of a revised specification).

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2. REVIEW OF TECHNICAL EVIDENCE

2.1 TESTS

2.1.1 Avro Wind Tunnel Ejection Tests

These tests were performed in the fall of 1957, at NRC, on Avro request.

Ejections of .07 scale models of occupied seats were made from a model of the Arrow aircraft and from a model of a sled test vehicle. Conditions, selected for the tests, were designed to represent full scale Froude numbers (V^2/gl). Full scale Mach and Reynold's Numbers were not truly represented in the tests.

Results of these tests cover cases of sea level, 20,000 and 40,000 feet of the altitude, and the speeds corresponding to Mach Numbers of from .5 to .85 (scaled down test Mach Numbers were below .25).

2.1.2 R.A.E. Wind Tunnel Tests

These tests were performed in the fall of 1955 at the Royal Aircraft Establishment, Farnborough, England (Ref. Test Note No. 626).

A full scale Martin-Baker Mk. 4 seat, with a dummy occupant, was tested at airspeeds of 120 ft./sec.

Results of these tests are in the form of drag and lift forces and of the pitching moments at the speed of 100 ft./sec., for the full range of pitching angles (covering 360°).

2.1.3 M.I.T. Wind Tunnel Tests

These tests were performed in 1953/54, some at the WADC ten-foot tunnel, other at the Naval Supersonic Laboratory (Ref. MIT Wind Tunnel Report No. 69).

A .097 scale model, of a typical occupied seat, was tested at wind tunnel Mach Numbers ranging from .6 to 2.0, at zero and 90° roll angles and at each of these roll position at full range of 360° of pitch angles of the seat.

Full scale Reynold's Numbers were not truly represented in these tests.

2.1.3 M.I.T. Wind Tunnel Tests (Continued)

Results are presented in the form of force and moment coefficients, in a co-ordinate system attached to the seat. Establishment of the drag and lift coefficients is pending completion.

2.1.4 U.S.A.F. Sled Ejection Tests

These tests were conducted at the project SMART (Supersonic Military Air Research Track), Hurricane Mesa, Utah, in the fall of 1957. A total of four full size Martin-Baker Mk. B5 seats, with anthropomorfic dummies, were ejected from a sled test vehicle, of a simple shape, not representing any particular aircraft (vehicle designed by the Coleman Engineering Co.).

The altitude of the tests was approximately 5,000 feet above sea level and the speeds of the sled vehicle, at time of ejection, were ranging from 455 to 559 Knots EAS.

All phases of ejection were tested, including the separation of the dummies from the seats and their landing by parachutes.

Results of the tests are in the form of comprehensive reports by Coleman Engineering Co., containing the records of rates of rotation, of accelerations, of pressures of the dummies, and of the trajectory data.

Ejections at speeds up to 500 Knots EAS may be rated as fully successful, while the last two ejections, at 550 and 559 Knots showed a deficiency in the operation of the drogue parachute deployment system.

2.1.5 Grumman Sled Ejection Tests

These tests were conducted as part of qualification testing of F9F-8T, Cougar-trainer aircraft, at the U.S. Naval Ordnance Test Station, China Lake, California, in 1957.

A total of 10 full size Martin-Baker Mk. A5 seats, with anthropomorfic dummies, were ejected from a representative fuselage, mounted on a sled. The speeds of the fuselage, at time of ejections, were ranging from 95 to 616 Knots EAS, and two seats, from the front and from the rear cockpit, were fired in sequence during each sled run.

The highest speed of successful ejection was 530 Knots EAS, while at 616 Knots, there was a failure in the parachute deployment system, of similar nature to that in the USAF test program.

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2.1.6 Grumman Ejection Tests From an Aircraft

These tests were supplementary to tests of Paragraph 2.1.5.

A total of 10 ejections of Martin-Baker Mk. A5 seats, occupied by the anthropomorfic dummies and by a live man (in one test only), were carried out from the Cougar-trainer aircraft, in 1957.

The altitudes of ejections were ranging from sea level to 14,500 feet, and the speeds were ranging from 57 to 457 Knots EAS. The live ejection was made at sea level and at speed of 122 Knots.

2.1.7 Avro Stationary Ejection Tests

These tests were performed at Avro, in 1958.

A total of 3 ejections of Martin-Baker Mk. C5 seat, with anthropomorfic dummies, were made from a stationary Arrow aircraft fuselage (Ref. A.T.R. No. 2803/1, by C.J. Austin).

These tests were arranged to check the first stage of the ejection, up to separation from the cockpit. They showed an excessive sliding of the dummies, forward on the seat.

2.1.8 Martin-Baker Tower Ejection Tests

These tests have been arranged to check the problem of sliding forward, by means of ejecting live men. A report, covering these tests is pending completion. It appears that the live men do not slide forward as much as dummies.

2.1.9 Avro Tests of Delays in Escape

These tests have been performed at Avro, using Arrow aircraft mockup, to check delays in the escape procedure (Ref. Report No. 70/HUFAC/1, by R.E.F. Lewis).

2.2 THEORETICAL INVESTIGATIONS

2.2.1 Theory of Trajectories

This theory has been generalized and systematized to allow for dealing with ejections of occupied seats from aircraft in any flight configuration. Also graphs have been established for the Arrow escape system which show conditions required to miss the fin of the Arrow aircraft (Ref. Report 70/SYSTEM 24/89, by K. Korsak).

2.2.4 Effect of Aircraft Altitude on Rates of Rotations of the Seat - (Continued)

(2) At the same speed of 560 Knots, at higher altitude, the initial rate of tumbling, due to higher drag coefficient at higher Mach Numbers, is expected to increase slightly, in the positive direction.

(3) At higher speeds, of up to Mach 2.00 at 31,000 feet, the initial rate of tumbling will proceed to increase in the positive direction, the extent of this change being unknown.

(4) In the initial position (as the seat leaves the aeroplane) the resultant pitching moment is always negative. This moment tends to accelerate the tumbling in the negative direction.

(5) Generally speaking, as a function of the seat angle, the moments, acting on the occupied seat, have a sinusoidal character, with zero values at 4 equidistant points, approximately 90° apart. One of these points is at approximately -45° with respect to the initial seat position. At this point the seat is statically stable. Incidentally, at this position the drag coefficient is at its maximum. Condition of dynamic instability is that, at the time of reaching the statically stable position, the kinetic rotational energy of the seat must be adequate to overshoot beyond the stable region of the moment versus angle of position curve.

In all sled tests up to date, the seats were dynamically unstable. However, the wind tunnel tests indicate that, at higher Mach Numbers, the seats may become dynamically stable. Due to Reynold's Number of the tests being non-representative, proper answer as to the dynamic stability, however, may be obtained only by full scale tests.

3. EVALUATION OF THE SUITABILITY OF THE MARTIN-BAKER MK. C5 SEAT

Based on the evidence of Paragraph 2, the following evaluation of the suitability of the Martin-Baker Mk. C5 seat, for the Arrow aircraft escape system, is presented.

3.1 FIN CLEARANCE

The fin clearances, as affected by the shape of the escape trajectories, are discussed below.

3.1.1 Equivalent Air Speed (EAS)

By definition, the equivalent air speed is a speed at sea level which produces the same dynamic pressure $q = \rho/2\ u^2$, as the given speed at a given altitude.

Considering the high speed portion of the Arrow aircraft flight envelope, the constant EAS border line starts from a sea level point of Mach 1.06 and ends at a point of Mach Number 2.00 at an altitude of approximately 31,000 feet above sea level.

The wind tunnel tests indicate that at Mach Number 1.06 the aerodynamic drag coefficient already has climbed considerably from its low speed value and that further climb of it is not too spectacular (about 12%).

Assuming that, although the Reynold's Numbers are non-representative, from the point of view under consideration, the wind tunnel tests are trustworthy and it can be concluded that:

(1) With the seat at a given trim (pitch) angle, conditions affecting the trajectory of the seat are the most critical at the altitude of 31,000 feet, Mach 2.00. However, these most critical conditions are exceeding the sea level conditions only by a small margin (by about 12%).

(2) Should, at the altitude of 31,000 feet and Mach 2.00, the rate of tumbling be different from that at sea level, Mach 1.06, the altitude trajectories may differ from those of the sea level by an appreciable margin.

3.1.2 Ejection Velocity

The seat gun ejection velocity, at the time of separation of the seat from the aircraft, depends on the characteristics of the explosive charges of the gun, on the weight of the occupied seat and on other forces acting on the seat parallel to the gun axis (aerodynamic, friction, lanyard).

The ejection velocity affects the trajectories in that the lower the velocity, the smaller the fin clearance.

3.1.2 Ejection Velocity (Continued)

3.1.2.1 Weight Effect on Ejection Velocity:

A study of the internal ballistics of the ejection gun indicates that the higher the resistance loads are, the higher the pressure build-up in the gun chamber, the faster the rate of burning of the explosive charges and the faster the rate of release of the chemical energy which is being converted into the kinetic energy of the seat. This produces a self-compensating effect. If the time of burnout is always longer than the longest time of the full gun stroke, which with the Martin-Baker seats is the case, the self-compensation is the most effective and, as a result, increase in weight does not produce appreciable reduction in the ejection velocity.

3.1.2.2 Explosive Charge Effect on Ejection Velocity:

For the Mk. C5 seat, Martin-Baker Co. has modified the explosive charges a few times and, as a result, there is a choice of either "standard" or "reinforced" cartridges.

U.S. Navy uses the standard type. Avro accepted the reinforced type, however, there seems to be an excessive scatter of the ejection velocity results, and the matter is not yet fully clarified.

Without exceeding the limit of 250 G/Sec. of the acceleration rise and the limit of 20G of the accelerations, with the Mk. C5 seat gun stroke of 72.75 inches, the theoretical maximum velocity achievable is 86.5 f.p.s. The reinforced type cartridges are claimed to produce a 90 f.p.s. velocity which means that the above mentioned limitations are exceeded.

The trajectory considerations are based on an assumption that the uniformity of the charges will be improved to give, at the full temperature range, a minimum velocity of 85 f.p.s.

3.1.3 Modes of Tumbling

Tumbling characteristics have been described in Paragraph 2.

The direction and the rate of tumbling affect the "effective" lift and drag coefficients of the first part of the trajectory, i.e. the trajectory from the point of separation to the point

3.1.3 Modes of Tumbling (Continued)

of passing over the fin. In the most critical cases within the flight envelope, in order to miss the fin of the Arrow aircraft, the "effective" C_L/C_D ratio must have certain minimum value. Without tumbling the actual C_L/C_D is below this value which means that the seat would not clear the fin.

However, a comparatively moderate tumbling is sufficient to clear the Arrow aircraft fin at speeds of up to 700 Knots EAS (equivalent to Mach 2.00 at 31,000 feet above sea level).

3.1.4 Weight of Occupied Seat

The weight of the occupied seat affects the trajectories directly, as well as indirectly, by affecting the ejection velocity and the time available for rotation, and hence the "effective" aerodynamic forces.

Trajectories are affected by the weight directly, in a reverse proportion to the effect of the aerodynamic drag coefficient, ie. an increase in weight is equivalent to a reduction of drag.

A weight increase produces a direct effect of an increase in the fin clearance (this is partly overshadowed by a decrease in the ejection velocity).

3.1.5 Fin Clearance Conclusions

3.1.5.1 At speeds of up to Mach Number .94, there is no danger of collision of the occupied seats with the fin, except in the case of a misfire.

3.1.5.2 At speeds exceeding Mach Number .94, due to the lack of confirmation by tests, the matter of the fin clearances is not yet fully clarified. Theoretical investigations indicate that tumbling of occupied seats in free flight after ejections produces a beneficial effect, in that it changes the lift in the positive direction, thus increasing the fin clearances.

3.1.5.3 Sled ejection tests, even if successful up to the speed of 700 Knots EAS, would not demonstrate what might happen in a high altitude, high Mach Number case.

3.1.5.4 In order to check the fin clearance in the most critical case, an ejection of the full size occupied seat should be done at 31,000 feet and Mach 2.00.

3.2 AERO-MEDICAL CONDITIONS

Paragraph 3.1, dealing with the fin clearances, gives an evaluation of conditions required to eject the seat occupant "in one piece" from the Arrow aircraft. The next step is to investigate conditions required to bring the occupant to a safe landing and in an unharmed condition.

3.2.1 Spinal Accelerations

From the dynamics point of view, the human body is composed of elastic elements (mostly bones) capable of carrying loads, and of soft tissue (including muscles), attached to these elastic elements.

Dynamically, the spine is an elastic column, with masses of various magnitudes attached to it at irregular intervals of its length.

Due to its elasticity, the seat cushion forms part of the dynamic system of the seat occupant.

Dynamic response of separate masses depends on the rate of change of the input acceleration of the seat. At high rate of change of the input acceleration, accelerations of the separate masses exceed the magnitude of the input acceleration and may cause high inertia loads of the spine.

In the Arrow escape system, part of the seat cushion is the R.C.A.F. survival pack. It has been designed and tested on an ejection tower, to eliminate as much as possible, its dynamic effect on the seat occupant. It is believed that with this survival pack, the maximum allowable rate of change of the seat acceleration is 250 G/Sec.

Some records of the sled ejections of anthropomorfic dummies indicate that, with the present design of the explosive charges of the Martin-Baker Mk. 5 seat, the rate of change of the seat accelerations may exceed the maximum allowable by a considerable margin when a live man is ejected.

Similar records of ejections of live men are not available.

3.2.1 Spinal Accelerations (Continued)

Martin-Baker Co. does not believe that there is a problem, however, this company should obtain positive proof that there is no problem, in the form of an oscillograph record of instantaneous accelerations of separate parts of the seat occupant's body. This is not included in present arrangements made with the vendor.

There is no doubt that, if required, the explosive charges may be improved to provide a uniform rate of change of accelerations and from this aspect the Martin-Baker Mk. C5 seat is acceptable for the Arrow aircraft escape system.

The maximum acceleration of the seat with reinforced type cartridges (Ref. Para. 3.1) will exceed 20G limit, if these cartridges, as claimed by the Martin-Baker Co., will produce the ejection velocity of 90 f.p.s. However, the 20G aero-medical limitation is not an absolute figure, and there may be no harm done to the spine if this limit is slightly exceeded.

A high ejection velocity is a very desirable feature, not only from the fin clearance point of view, but also from the aspect of low altitude, low speed ejections.

Another problem, associated with spinal accelerations, is the adequacy of the restraints of the head and the chest of the seat occupant. Due to a tapered down shape of the personal parachute and due to the space taken by the drogue parachute container, the Martin-Baker seat is more critical than other American seats from the point of view of possible falling of the head and of the chest forward. On this seat, in the normal seating position, the angle between a line joining the centre of the head with the centre of the hips is inclined approximately 10° to the line of ejection. The shoulder strap becomes loose on shrinking of the spine, and hence this angle may be increased considerably before the straps become effective.

With the face curtain held by the hands, there should not be any problem. At higher speeds, however, the wind blast on the arms may cause the hands to release the curtain during the ejection. Also, on ejections using the emergency "D" ring, located between the knees, the curtain is not effective. The Martin-Baker Co. did not agree as yet to do anything about this possible deficiency.

An improved chest and head restraint, however, is possible without radical changes of the seat.

3.2.2 Transverse Decelerations

For the case of a stabilized seat, there exists a commonly accepted curve of allowable decelerations versus time, but the effect of tumbling on this curve is not clearly defined. This matter is now under study at the Institute of Aviation Medicine (by S/L R. Stubbs).

Generally speaking, the aero-medical criteria of allowable accelerations are only approximate, based on few cases of accidents in which certain injuries occured.

Regular test programs for a given set of conditions, such as a combination of rotation with deceleration, cannot be undertaken, as it would require endangering of lives of participants in such programs.

Considering that comparatively moderate rotations, of the order of $\pm$ 500°/Sec., and of short duration do not adversely affect the ability to withstand the transverse accelerations, it appears that the Martin-Baker Mk. C5 seats do perform satisfactorily on ejections from Arrow aircraft, flying at 600 Knots at sea level. This speed corresponds to Mach Number of .90.

Considering the most critical case, 700 Knots (Mach Number 1.06) at sea level, the wind tunnel tests indicate that the drag coefficient from Mach Number .90 to 1.06 increases by approximately 7%, hence the decelerations increase by approximately 45%. Considering now the most critical altitude case, at 31,000 feet above sea level, and at a speed of 700 Knots, due to the Mach Number increase to 2.00, the deceleration increase of additional 12% may be combined with the seat stabilization at the maximum drag trim angle. This additional deceleration effect of the high altitude may be compensated by a reduction in the rate of rotation which is predicted by the wind tunnel tests. In conclusion of these considerations, it may be said that at 700 Knots EAS decelerations may exceed by some 50% the limit of the "possible injury" and by some 20% the limit of the "fatal injury", and possibly by a greater margin if the rotation effect is detrimental.

If there is a need for a reduction of excessive decelerations, this can be done either by an increase of the weight of the seat, or by an addition of a rocket, or by replacement of present ejection gun by a rocket-gun combination of a type similar to the known Talco "rocket-catapult".

3.2.2 Transverse Decelerations (Continued)

Alternatively, a compromise may be accepted by restricting the ejections to a speed, established by high altitude tests, and of an order of 650 Knots EAS.

3.2.3 Flailing of Limbs and Head

In its present configuration, the Martin-Baker Mk. C5 seat is equipped with adequate restraints to prevent flailing of the legs. However, restraints of the hands and side supports for the head do not exist. Martin-Baker Co. have promised to investigate the feasibility of incorporation of these restraints into their Mk. C5 seat. Except for what has been report by Mr. W. Farrance upon his return from the U.K., the results of the investigation are not known. Progress is apparently mode and there is no reason why the Martin-Baker Mk. C5 seat would not lend itself to the provision of adequate restraints.

3.2.4 Wind Blast Protection

Except for the face blind curtain which is not always in use, the seat does not have any feature of protection against wind blast. It is, however, possible to develop an improved type of clothing and helmet to achieve adequate protection, without any help from the seat.

It is understood that a new clothing and helment are under development under the R.C.A.F. supervision. It is not known at this time, if an adequate equipment already has been developed. Since Avro has no intention of taking part in the development of personal equipment, it is logical that the responsibility for this aspect of the escape system should be surrendered to the R.C.A.F.

3.2.5 Gun Bending

Bending of the seat ejection gun in the aft direction reduces the vertical component of the ejection velocity. As it has been demonstrated by tests, at speeds up to 560 Knots at 5,000 feet above sea level, such bending is insignificant. Since, however, in cases covered by tests, the drag load on the occupied seat only slightly exceeded 50% of the design load, the situation may change rapidly at higher speed tests. Should the gun deform significantly, it will have to be strengthened, which is feasible.

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3.2.6 Spinning on Descent

While rolling and pitching angles of the seat are stabilized as soon as the drogue parachute opens, spinning around the yaw axis may proceed unrestrained until the seat reaches the altitude of separation of the occupant from the seat. Rates of such spinning may be established only by means of high altitude ejection.

4. EJECTION CONTROL

An introduction of an additional mode of the ejection control, allowing the pilot to eject the navigator, is considered by Avro to be a mandatory requirement. There is not reason why the Martin-Baker Mk. C5 seats would not be suitable to be equipped with such an arrangement.

During his visit to Avro, Mr. J. Martin was approached on this subject and promised to investigate, however, nothing new has been reported by Mr. W. Farrance and there is a need for a more precise handling of this matter.

Additional restraint, required to automatically place the navigator in a "ready-for-ejection" position, is the same as that described as being required to prevent leaning forward (Ref. Para. 3.2.1.)

5. SEAT DESIGN RECOMMENDATIONS

5.1 The investigations show that:-

5.1.1 What has been said of the lack of proof of adequacy of the Martin-Baker Mk. C5 seat, may equally well be said of any other seat of comparable design.

5.1.2 There is no evidence that any existing deficiency of this seat cannot be rectified.

5.1.3 The Martin-Baker Mk. C5 seat has been adopted earlier as suitable for the Arrow aircraft.

5.2 Therefore:

5.2.1 The present recommendation is to retain the basic Martin-Baker Mk. C5 seat, and to initiate the following steps, leading to its improvement:-

5.2.2 To prepare and to issue a new specification of the seat which would contain all requirements in line with the latest thinking of the Technical Department.

5.2.3 To negotiate an agreement with the Martin-Baker Co., whereby the seat would be treated on equal basis with other items of the Arrow aircraft equipment, namely that the vendor would be compelled to adhere to all points of the new specification, regardless of other preferences and opinions which he might have.

5.2.4 To entrust the Martin-Baker Co. with the responsibility for the development of the seat, with Avro participating in a monitoring capacity. By virtue of this arrangement, the Martin-Baker Co. would have to be awarded a development contract, also covering the test program.

Note: An alternative to this arrangement is:- to ensure that the vendor agrees to incorporate all modifications, developed at Avro; in this case Avro would undertake the development program. (It is doubtful that the vendor would agree to such an arrangement).

5.3 DEVELOPMENT PROGRAM

Since, in its present configuration, the Martin-Baker Mk. C5 seat does not match the Arrow aircraft performance, a development program is inevitable.

While theoretical investigations are a powerful tool for directing the development, they cannot be substituted for tests.

A review of the methods of testing, required to accomplish the program, is presented below:-

5.3.1 Wind-Tunnel Aerodynamic Tests

The available information is helpful in reaching certain conclusions, but is not sufficient to provide all the answers.

Additional wind-tunnel tests, would be beneficial and, if results were obtained in time, may reduce the extent of other tests.

5.3.2 Wind-Tunnel Dynamic (Ejection) Tests

Series of wind-tunnel ejection tests, covering the speed range of up to Mach .85, have been recently completed at

5.3.2 Wind-Tunnel Dynamic (Ejection) Tests (Continued)

NRC, using, as a vehicle, a model of the Arrow aircraft, as well as a model of a sled test vehicle.

Owing to the low Mach Numbers involved (actual scaled down test Mach No. did not exceed .25), these tests are of little value for the future development program, and it is doubtful if it is feasible to cover the speed range of up to Mach 2 by similar tests in a representative manner.

However, these tests contributed to the program by providing information as to the effect of the shape of the launching vehicle on the performance of the seat in free flight.

5.3.3 Tower Ejection Tests

These tests provide a convenient way of checking the dynamic response, of separate parts of the seat occupant's body, to acceleration of the seat on ejection, a way of checking the accelerations of the seat, as governed by the performance of the ejection gun, and a way of checking the ejection clearance envelope for the cockpit design.

The tower ejection tests are relatively inexpensive and have been extensively used by the Martin-Baker Co. to check various aspects of design of their Mk. 5 seat.

Such tests may still be required to make sure that the seats are capable of meeting the newest specification requirements.

5.3.4 Sled Ejection Tests

Based on the low speed wind-tunnel ejection test data, and on theoretical considerations, it appears that the shape of the launching vehicle does not appreciably affect the performance of the seat in free flight.

Hence, for development of the seat, a representative fuselage is not required. A simple sled vehicle, such as that designed and built by the Coleman Engineering Co. and used by the USAF for testing the Martin-Baker Mk. B5 seat, is sufficient.

Such tests should be conducted up to the speed of 700 Knots EAS, or more, to check the following:-

5.3.4.1 Sequence of events (ejection, deployment of parachutes, separation from the seat, etc.)

5.3.4.2 Strength of the parachutes and of the ejection gun,

5.3.4.3 Wind blast pressures and effectiveness of the body restraints.

5.3.4.4 Rates of rotations after the ejection

5.3.4.5 Trajectories of free flight, as affected by performance of the ejection gun, etc.

Because of the convenience of this method, the sled ejection tests have now become a mandatory part of any seat development program. Avro should make full use of other sled ejection programs, such as the one covering the USAF tests of the Mk. B5 seat.

Since, however, none of the existing programs cover the full range of the Arrow aircraft performances, and since essentially these are not development programs, additional tests will have to be arranged.

With the use of liquid-propelled locomotives which will soon be available, the price of such tests should be much reduced.

Although very useful for the seat development, the sled ejection tests have their limitations, in that they cannot cover the high altitude cases which are the most critical as far as the decelerations, the trajectories, the gun bending, the spinning and the wind-blast effect are concerned.

5.3.5 High Altitude Ejection Tests

For the reasons outlined above, the sled ejection tests should be supplemented by some kind of high altitude ejection tests.

Such tests could be done by ejecting anthropomorfic dummies from a vehicle travelling at speeds up to Mach 2, at altitudes of from 60,000 to 30,000 feet above sea level.

The vehicle may be either an aircraft, such as the Arrow, or a rocket propelled test vehicle, or a bomb, dropped from a balloon.

5.3.5 High Altitude Ejection Tests (Continued)

The simplest would be to complete as much development as is feasible using the sled ejection method, and to supplement it by high altitude ejections, using the Arrow aircraft, as a vehicle.

6. ARROW AIRCRAFT ESCAPE SYSTEM AS A WHOLE

6.1 As an item of the Arrow aircraft equipment, the seat should be dealt with separately, it should undergo its own development program (by the vendor) and it should be qualification tested to Avro satisfaction.

The escape system as a whole has been designed by Avro and it should be developed under a direct Avro supervision.

In addition to the seats, the system comprises the canopies, their locking and operating mechanisms, and other items of cockpits, taking part in the escape.

Since it is anticipated that an additional mode of ejection control, enabling the pilot to eject the navigator, will be introduced, in addition to existing interlocks between the canopy and the seat operating mechanisms, an interlocking of the pilot's and the navigator's operating mechanisms will be required.

Operation of the canopies is affected by airloads, as well as by cockpit pressurization. There is also a certain amount of inter-dependency, in that the operation in one cockpit, say pilot's, depends on conditions in the other cockpit, say navigator's , and vice versa.

In their open position, the canopy shells are subject to possible buffeting and/or flutter at high speed. This aspect should be studied from the point of view of interference with the escape.

6.2 DEVELOPMENT OF THE SYSTEM

As it was said earlier, the escape system should undergo its own development program. Being of an emergency type, this system may not be used in any other phase of the Arrow development program, hence it should be tested in a program, specifically assigned to deal with the escape.

6.2.1 Stationary Ejections

Using a structurally representative front fuselage and canopies, ejections of Martin-Baker Mk. C5 seats should be conducted, to check the operation of the system.

In order to establish the effects of symmetrical and asymmetrical structural deformations, the fuselage and the canopy loads should be applied during these tests, to represent the most adverse conditions which might cause a malfunctioning of the canopy locking and/or operating mechanisms.

6.2.2 Wind Tunnel Tests

Such tests seem to be the most convenient way to check the canopy shells for buffeting and/or flutter. For this purpose only the uppermost section of the front fuselage may be used in one of the high Mach wind tunnel facilities.

6.2.3 Sled Ejection Tests

Sled ejection tests of the system should be treated as separate tests from those required for the seat development, for the following reasons:

6.2.3.1 The system sled ejection tests require a more elaborate fuselage, with the upper section representative of the Arrow aircraft, and this may hold up the seat development.

6.2.3.2 The system sled ejection tests should be arranged having seats ejected from both the pilot's and the navigator's cockpits, which in early seat development stages, would be wasteful.

6.2.3.3 The number of sled runs required for the system tests may differ considerably from the number of runs required for the seat development tests.

6.2.4 Ejections From A Flying Vehicle

As it was pointed out earlier, the sled tests cannot properly simulate the most critical combination of high Mach Number at a given dynamic pressure. Hence, the sled tests of the system should be supplemented by at least one check of operation at Mach Number 2.00 at the altitude of 31,000 feet above sea level.

6.2.4 Ejections From A Flying Vehicle (Continued)

Use of a specially designed vehicle, such as one of those described in paragraph 5.3.5, would allow to eject both crew members. However, if an aircraft is used, the cycle may stop at the stage of opening of the pilot's canopy.

7. SYSTEM DESIGN AND DEVELOPMENT RECOMMENDATIONS

Since the design of the system is completed, no changes should be contemplated, unless it is proved beyond doubt by tests that something is inadequate.

Development tests, leading to the establishment of the reliability of the escape system, and the reliability of the locking and operating mechanism of the canopy in particular, should be arranged as soon as possible.

ARROW ESCAPE SYSTEM TESTS

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Arrow Project Office
Avro Aircraft Limited

FORM 1749 A

LIST OF CONTENTS

1. SUMMARY

This report sets out the proposals of Avro Aircraft Limited for the proof testing of the ARROW Aircraft Escape System. This proposal defines the test media available and the functions and relative parameters of the escape system to which they apply.

Table 1 of this report summarizes those tests to date, relative to the proof testing of the ARROW system. It further indicates those areas still requiring proof testing of the various elements, and the test medium by which the data may be acquired. In addition, the table indicates those tests performed on Martin Baker MK5 ejection seats by other agencies. It should be recognized that considerable testing has been carried out by other agencies relative to escape systems in general. Only by a broad extrapolation is it possible to associate these results when considering the applicability of these tests relative to the ARROW system.

2. GENERAL

2.1 Object of Test Program

The object of the test program is to demonstrate the effectiveness of the complete escape system of the aircraft. This object may be regarded as sufficiently realized if the tests show that, under all conditions prescribed

(a) the emergency canopy opening system functions satisfactory without causing hazard to the crew,

(b) the crew ejection system functions correctly, with safe and satisfactory separation of the crew members from the aircraft and its services,

(c) the pre-separation performance of the man-seat system and personal equipment of the crew members in such that satisfactory operation is assured without suffering injury or being subjected to unacceptable accelerations,

(d) the satisfactory separation of the man-seat combination is accomplished and subsequent free fall and controlled descent occur without apparent danger.

NOTE: The possible need for escape system development in order to achieve this object is acknowledged.

2.2 Scope

The scope of the proposed test program will be limited to that of proof testing the escape system for conditions within the flight envelope requirements of the ARROW aircraft. It should be recognized that several of the elements of the escape system will be tested under simulated operational conditions. Therefore the validity of the results of these individual tests may, when considered on an accumulative basis, be inconclusive with respect to the overall function of the escape system.

2.3 Test Method

It is proposed that utilizing test methods available and existing test data, a comprehensive analysis of the escape system will be possible. The test methods available are as follows:

(a) Static rig
(b) Wind Tunnel
(c) Ejection Tower
(d) Spin Tower
(e) Ballistic Missile
(f) Rocket Sled
(g) A/C Flight

These methods and how they would be applied to the various parameters of the escape system are discussed in the following paragraphs.

3. DISCUSSION

It is not intended to discuss in detail the tests completely, but rather to give the broad idea, nature and purpose of these tests. Detail arrangements and planning will be accomplished by the personnel involved who will be able to modify the program to suit requirements.

Referring to TABLE 1, the following paragraphs discuss the present situation and required tests relative to the ARROW system. In addition, a short summary on similar tests that have been undertaken by other agencies is included.

3.1 Canopy

Considerable testing has been carried out on the ARROW configuration using the Static[1] and wind tunnel[2] methods. Further tests are not recommended via these mediums, but rather by ballistic missile, sled tests or flight trials. Ballistic missile method would involve the design and manufacture of a structure simulating the cockpit area and escape system of the ARROW. The missile would be dropped from an aircraft or balloon in free fall or augmented flight and an escape sequence actuated. This method could provide a full range of dynamic flight characteristics. The project would be expensive and data would present difficulties from a telemetry standpoint. Photographic coverage of any sequence would be limited and the recording of the event would rely mainly on tape recorded signals. In the main this method may be inconclusive due to the aforementioned items and the marginal control over the speed range required.

An ARROW sled program can provide suitable if not completely representable data, using a controlled and fully recorded medium. The opportunity of recording the effect of alternating pilot and navigator in ejection order can be observed using a complete, representative, ARROW sled configuration.

Flight trials would also produce the required data, but would be applicable to the rear cockpit only. The mechanics required to enable the canopy to be closed after ejection, may produce technical problems and reduce the representative configuration such as to vitiate the results. The instrumentation problems of telemetry and photography associated with the ballistic method would also apply to flight trials. Of necessity, any proposal using this medium could only be conducted after considerable experience of the handling qualities of the aircraft had been established. Therefore, considering the aforementioned items, the safety factor and the time element, they may remove this medium from any consideration as a firm proposal.

3.2 Seat Ejection

Seat ejection tests using the M/B MK.5 seat have been conducted by Avro using the static test aircraft[1] and wind tunnel[3] methods. In the main these tests have been considered satisfactory to the extent to which they were conducted. In addition, other agencies have conducted tests on a similar M/B MK.5 seat using the static rig[4], ejection tower[5], sled tests[6] and in-flight trials[7]. These latter tests are representative in environment only, but are not necessarily applicable when considering the ARROW complete system. It may therefore be said, that in the ARROW complex a condition may exist which may not be apparent and may nullify their applicability. However, it is feasible to consider further wind tunnel tests using an ARROW configuration which would supplement data obtained from other agencies relative ejection tests on rocket sleds. In addition, it would be advisable to consider further ejection tower tests to provide data relative to the satisfactory operation of the survival kit, personal restraints and clearance of cockpit protuberances.

When considering the medium of ballistic, sled or in-flight test programs and having regard to the complications relative to canopy operation and instrumentation in-flight, the following observation is made.

The entire area to be proof tested relative to the ejection seat may be well satisfied using the latter two of the aforementioned mediums. A certain advantage would be gained in utilizing an Avro sled as the complete elements of the escape system would be available. The only supplementary tests to be considered in this advent would be via the ejection tower, however, they would not be mandatory.

3.3 Restraints

The mediums used to date to test the ARROW configuration have been the static rig[1] and ejection tower[5]. Further tests are required and may be evaluated by several of the mediums listed in TABLE 1. As in the discussion covering the ejection seat, those recommendations would be applicable when considering restraints and their possible dèvelopment in the future.

3.4 Egress Clearance

The static test rig[1] and ejection tower[5] have been utilized to date to obtain data relative to the ARROW configurations. As would be apparent, only a truly representative specimen would be of value in obtaining data relative to this element. It would not be possible to obtain this data via the rocket sled method unless it were to an AVRO specification. In-flight testing would be acceptable if the required closing mechanism for the canopy did not contribute to an unrepresentable configuration. It must be acknowledged that the rear seat configuration would be the only tests possible for any flight case. Furthermore, the most sophisticated dummies are still not completely representative of the average human frame.

3.5 Wind Blast

The data available relative to these elements has been acquired solely via foreign sled test method[6]. All other data available is relative to a configuration other than that to be expected for the ARROW aircraft. The aeromedical field; however, has produced considerable data which is applicable to the ARROW configuration when considering the effect rather than the cause, viz. clothing, seat flight characteristics.

When considering future tests relative to this element, the methods listed in TABLE 1 afford equal opportunity to acquire the relevant data.

3.6 Accelerations

There is no evidence produced to date relative to the ARROW configuration qualifying the accelerations other than the unscheduled results of static tests[1]. Other tests to date have been conducted on ejection seats that are similar in construction, but differ in the propellant. There is abundant information relative to the aeromedical limits on this element, but of necessity this area must be investigated utilizing the specific ARROW configuration.

3.6 Accelerations (Continued)

The media listed in TABLE 1 all satisfy the test requirement of this element of the escape system. The Anthropomorphic/metric dummy affords the best opportunity to record this data and the rocket sled method perhaps is the best medium to record this information.

3.7 Trajectories

The wind tunnel tests[3] relative to this element were conducted by Avro at NAE using a .04 to .07 model. These tests were conducted to investigate the similarity of results when compared to a sled model for which a complete set of data was available. The recording apparatus was photography and a considerable degree of license was used in interpreting the results of these tests.

Of the apparatus available for recording the trajectory data, the aircraft flight case is perhaps the most expansive. Factors of "g" may be considered and, therefore, representative cases investigated. However, as the recording apparatus invariably is photography the flight case may well be ruled-out as impractical on this level. The rocket sled facility whether Avro or foreign, provides the best medium for recording these trajectories by photography, by virtue of the solid nature of the earth on which the cameras are mounted. It is then possible to calculate the effects that "g" would have on any recorded trajectory and predict the fin clearance for the ARROW aircraft. There are of course other elements of the escape system which contribute or detract from this vital requirement of fin clearance.

3.8 Tumbling

There has been no evidence to date produced by Avro relative to this element of the ARROW escape system. The element, however, is critical to survival as it contributes to the lift characteristic of the seat and detracts, in that a malfunction may occur due to entanglement with the M/B MK.5 particular drogue system.

3.8 Tumbling

In addition, certain aeromedical[8] considerations are connected with this element and data relative to all these requirements is necessary to qualify the ejection seat. It is not possible to divorce the tests of this element from the ARROW system; however, there is evidence recorded relative to the M/B MK.5 configuration produced by other agencies.

Of the mediums available to record the required data, the rocket sled tests, either AVRO or foreign, are by nature of the recording apparatus, photography and telemetry, perhaps the most suitable medium.

3.9 Seat Stabilization

All evidence to date relative to this element of the ARROW system has been provided by rocket sled and flight test methods. Again the configuration that has been tested was similar to the M/B MK.5 seat in most respects. Considerable testing via this medium has been undertaken by the USAF, but on decidedly different configuration which cannot be interpreted as of any great value in assessing the M/B seat.

As in the previous paragraph (3.8), by the nature of the data producing apparatus, the rocket sled facility lends itself to the advantages for tests of this element. The immediate need for data in the higher speed ranges does not make it advantageous to rely on future tests by other agencies.

3.10 Deceleration

The problem of deceleration[8] is closely associated with the satisfactory operation of the M/B MK.5 duplex drogue system. This particular element is qualified within the limited speed range (550K EAS) as tested by other agencies. Therefore, if the existing configuration can be proof tested satisfactorily up to the higher speed range expected of the ARROW, the aeromedical considerations need not apply.

3.10 Deceleration (Continued)

The test mediums available are individually satisfactory with perhaps the considerations as discussed in Section 3.9 still applying.

3.11 Spinning

The abundant data[8] produced by other agencies relative to this element must not be considered as evidence of qualification of the M/B MK.5 seat. This evidence is relative to seat designs presently under development in the United States on totally different configurations. There is also very definite evidence as to the aeromedical problems associated with spinning, but this evidence need not apply to the M/B MK.5 seat due to the system of stabilizing drogue chutes.

The data relative to the M/B seat has been provided by M/B and the USN and presents an acceptable argument as to the satisfactory operation of the seat relative to this element. There is, however, a problem of coning associated with any descent by parachute which can be considered as part of the ejectees controllable responsibilities. It is, therefore, recognized that further tests on this element are not mandatory for the ARROW system.

3.12 Separation

Again this element of the ARROW system is closely associated with the satisfactory operation of the M/B MK.5 duplex drogue system. As such the recommendations as previously listed in 3.9 will apply to this element.

3.13 Deployment

When considering all the elements of escape relative to the ARROW system the function of deployment of drogue and main chute appear to be the most critical. The evidence to-date, obtained from other agencies, illustrates the need for additional proof testing of this element with particular reference to the duplex drogue system. Of the available mediums by which this element may be qualified, none had produced the phenomena recently experienced in the rocket sled tests of the M/B MK.5 seat. A critical area of design is presently being investigated by the USAF however, there is no assurance that this

3.13 Deployment (Continued)

investigation will continue into the higher speed range expected for the ARROW. It is also possible to qualify this element via the spin tower or in-flight cases. Again however, the recording apparatus for the required data is subject to the operational conditions present in these mediums.

3.14 Rate of Descent

With regard to the state of the art relative to this particular element, there is perhaps no immediate problem to be considered. The data produced has been entirely from other agencies and is acceptable in that respect. Additional data however, would, as a matter of course, follow from the required proof testing of the other elements of the ARROW system.

3.15 Survival Pack

This particular element has no direct recorded test data relative to the ARROW System. The test data produced has been acquired via the static test rig and ejection tower. However, the configurations tested have not been representative nor as a result of a scheduled program of qualification. Considerable testing has been carried out on behalf of AVRO by the RCAF, but a qualification of this item is still necessary under the operational conditions to be expected in the ARROW system.

Of the medium available for these tests consideration should be given to tower testing, prior to the final proof testing under operational conditions. Final proof testing may be carried out utilizing the several methods noted in TABLE 1. It has not been possible to-date to acquire this data via sled programs controlled by other agencies. This problem could, as a matter of course, be eliminated with a more formal approach being taken.

4. CONCLUSIONS

Referring to TABLE 1 and the previous discussion, it is apparent that the desired objective may be satisfied by more than one specific program. The rational approach to the selection of any one particular program however, is influenced by factors of time, economics, environment, contractual and moral obligations.

Considering first a selective program, whereby an element or several of the elements are combined during a specific program.

The cockpit and canopy interaction must be considered together. TABLE 1 shows that the static rig plus wind tunnel must be used to explore the full impact these elements will have on the complete system. Therefore, if it is deemed adequate to complete only this requirement, then it is obvious that ballistic or sled test methods need not be considered.

Another consideration would be to link the elements of seat ejections with restraints and egress clearance. Limiting the object to investigations at this level may be justified on the basis of past experience and favourable conclusive results that may be obtained. Again considering only these requirements, it is apparent that static rig, wind tunnel and ejection tower will suffice. The need for the more expansive results that can be obtained by any of the remaining test mediums is null and void.

A new aspect of any proposed program must be considered at this juncture of these conclusions. If proof testing of all the foregoing elements are required and combined, then the philosophy of ballistic, rocket sled or flight test mediums is now more prevalent. The added dividend of obtaining results on the other remaining elements would also enter into this consideration.

In conclusion it is felt that the combined interaction of all of the individual elements of the entire system is critical and mandatory. This justification for a complete proof test will evince the need for the comprehensive program available through the use of the rocket sled medium based on the ARROW configuration.

APPENDIX A

TABLE 1

ELEMENTS OF ESCAPE SYSTEM		TEST MEDIUM: STATIC RIG	WIND TUNNEL	EJECTION TOWER	SPIN TOWER	BALLISTIC MISSILE	ROCKET SLED: AVRO	ROCKET SLED: FOREIGN	A/C FLIGHT
1	Canopy Function	+	+			θ	θ		
2	Seat Ejection	+ *	+ θ	+ θ *		θ	θ	θ *	θ *
3	Restraints	+		+ θ	θ	θ	θ	*	θ *
4	Egress Clearance	+		+		θ	θ		θ
5	Wind Blast					θ	θ	θ *	θ
6	Accelerations	+		θ *		θ	θ	θ *	θ *
7	Trajectories		+ θ				θ	θ *	θ *
8	Tumbling						θ	θ *	*
9	Seat Stabilization						θ	θ *	*
10	Deceleration						θ	θ *	θ *
11	Spinning								*
12	Separation						θ	θ *	*
13	Deployment				θ		θ	θ *	θ *
14	Rate of Descent					θ	θ	θ *	*
15	Survival Pack	+		+ θ					

+ AVRO - HAVE TESTED
θ AVRO - POSSIBLE MEDIUMS FOR REQUIRED PROOF TESTS
* FOREIGN - HAVE TESTED - SIMILAR CONFIGURATION

APPENDIX B

REFERENCES

Index No.	Title	Origin
1	Ejection Systems	Avro, Art No. 2803/1
	Canopy Function Tests	Avro, Art No. 2472/1 etc.
2	Wind Tunnel Testing	Avro, Memo No. 7233/31/J
	Wind Tunnel Testing	Avro, Memo No. 6601/08/J
	Wind Tunnel Testing	Avro, Report P/129
	Wind Tunnel Testing	Avro, Report P/149
3	Wind Tunnel Ejection Tests	Avro - (not issued to-date)
4	Static Ejection Tests	Grumman - No. 3033-01F
5	Ejection Tower Tests	Grumman - (no recorded no.)
	Ejection Tower Tests	Martin Baker Memo JM/AP/JS/Avro
	Ejection Tower Tests	Avro, Memo - 6467/02A/J
6	Rocket Sled Tests	Grumman - 3033/JB
	Rocket Sled Tests	Coleman - S.T.M. 75
	Rocket Sled Tests	Coleman - S.T.M. 76
	Rocket Sled Tests	Coleman - S.T.M. 77
	Rocket Sled Tests	Coleman - S.T.M. 78
7	Flight Test Program	Grumman - (no recorded no.)
8	Aeromedical Data	University of Cal.-Avro,Misc.No.5
	Aeromedical Data	Jr. of Aviation Medicine - Feb./57
	Aeromedical Data	CAI - Preprint 7/14
	Aeromedical Data	A.S.M.E. - Avro Lib - 54-A-230