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BOEING AEROSPACE COMPANY

Seattle, Washington

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Improved HAWK Ad Hoc Group Report (U)

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General H. A. Miley, USA
Commanding General
Army Missile Command
Alexandria, Virginia

Dear General Miley:

Reference: Letter of 3 May, 1973 from K. C. Emerson

The reference letter requested that I act as chairman of an ASAP Ad Hoc Group on Improved HAWK. The group was requested to investigate the latest missile in flight breakup and to report its findings to you directly. The terms of reference include the following questions:

a) What is the cause of the breakup?

b) Can this condition be corrected?

c) Should the condition be corrected?

The following summarizes our findings and recommendations.

A. PROBLEM AND APPROACH

Improved HAWK Missile Serial #275093 was test flown at White Sands on 13 April, 1973, in a multiple target test. Pertinent test conditions were:

Intercept Range	16 Km
Intercept Height	1.8 Km
Target Velocity	213 M/sec incoming, planned
Target Spacing	213 M horizontal, planned

Missile breakup occurred at approximately 23.4 seconds after launch following a sharp roll shortly before predicted intercept. This missile is one of the FY '69 production series modified to incorporate elevon servo changes. Although the telemetry records indicate some detailed differences in missile behavior due to the modifications, the loss of roll control and subsequent breakup of #275093 appear characteristic of earlier flights.

Missile Serial #275094, incorporating similar modifications, had been fired against a maneuvering target on August 30, 1972, scoring a direct hit. In the earlier flight, however, there were unpredicted pitch-yaw oscillations during the last four seconds of flight.

Thirteen tests of Improved HAWK against multiple targets have been analyzed by the prime contractor, Raytheon. These were conducted near the center of the critical spacing regime (200 to 1000 feet) and at co-speed. These included two R&D missiles, four Industrial Prototype missiles, six production missiles and one modified production missile. Of these thirteen, eight guided to intercept with miss distances of 0.0, 2.8, 3.7, 10.2, 16.7, 21.7, 24.8 and 26.9 meters. The other five lost control (39%) and four of these broke up before intercept.

The five missiles which lost control have the common element of terminal high g maneuvers in the region of very high Q right after the end of missile sustainer burn-out. The successful shots occurred beyond this range, at various ranges out to thirty kilometers. No shots were fired inside the motor burn range, since it was assumed that the illuminator would resolve targets at these ranges and hence there would be no multiple target problem to the missile.

Eleven tests of Improved HAWK against 6 g escape maneuver targets, with maneuvers initiated four to six seconds prior to intercept, were analyzed by Raytheon. These included two Industrial Prototype Missiles, eight production missiles and one modified production missile. Of these eleven, seven guided to intercept with miss distances of 0.0, 0.0, 2.4, 14.5, 25.6 and 38.5 meters. One of the eleven engagements resulted in a tail chase situation outside the recede zone of the missile; i.e., the target was chased away. The remaining three missiles (27%) lost control and broke up before intercept.

In all cases in which breakup has occurred, there has been an apparent characteristic sequence of elevons hard over, followed by loss of roll control, and subsequent breakup.

It seems conclusive that the breakup of #275093 on April 13, 1973, was not an isolated accident but is caused by the same fundamental factors as the earlier incidents.

The Ad Hoc Committee was convened consisting of the following members, in addition to the chairman:

J. Thomas	McDonnell/Douglas Corporation
L. Delaney	Martin/Marietta Company
A. Eaton	APL, Johns Hopkins University
B. Reese	Purdue University
D. J. Fink	General Electric Company
Col. D. Walsh	U.S.A. Air Defense School
Col. A. N. Champion	AMC Headquarters

The Ad Hoc Committee had four meetings to discuss the problem. Information and/or briefings were supplied primarily by the HAWK Project Manager's office; the Raytheon Company, and the MICOM Laboratories organization. Supplementary data was obtained from the intelligence agencies and associate contractors. These organizations were particularly responsive in a short time interval to the questions asked by the Ad Hoc group.

B. PERTINENT PROGRAM BACKGROUND

The HAWK Improvement Program was initiated in 1963 to upgrade Basic HAWK performance against the threat and to provide a more easily maintained system with improved reliability. We are advised that the principal objectives in the HAWK Improvement program were to provide: a better probability of kill against the entire target threat array in an electronic countermeasure environment; a certified round of ammunition that required no test and repair in the field by the user; and Ground Support Equipment that would improve the HAWK system response time and availability.

Both Basic HAWK and Improved HAWK are controlled by four elevons attached to the four delta wings. Pitch or Yaw commands in g's must be limited to avoid committing the elevon's control forces totally to pitch and yaw, leaving no reserve for roll control. As currently mechanized the commanded elevon deflection angle is electronically limited. Unfortunately as larger g's are commanded in pitch or yaw, the angle of attack increases and, due to roll-yaw-pitch coupling, the roll requirements also increase sharply.

The selection of autopilot axes is such that, when pitch and yaw are limited, the maximum combined maneuver forces are placed on one pair of wings rather than being distributed equally on both sets of wings.

There have been four major management/technical decisions in the program history which are pertinent to an understanding of the current problem and possible solutions. These are:

1) The decision at program start to retain unchanged the basic HAWK aerodynamic configuration, planform, and structural assembly attachments. A new wing was developed for Improved HAWK to the same load requirements as the Basic HAWK wing. These decisions constrained the IH design in both structural and performance aspects.

2) The decision at program start to design for improved capability against multiple targets by enlarging the warhead rather than improving the missile guidance. This decision resulted in a system effectiveness very sensitive to fuze performance as well as target vulnerability assumptions. For example, of the eight shots against multiple targets which did not break up, four had large miss distances (in excess of 16 meters or 50 feet).

3) The decision, in 1969, to raise the maneuvering target threat "g" level from 3 g to 6 g. As a result of analyses at that time the missile "g" and elevon deflection angle (δ) limits were increased. In retrospect the change may have pushed a marginally safe design into a flight region where loss of control is statistically probable.

4) The decision early in the program, whether conscious or by default, to rely on Basic HAWK wind tunnel data and to do a minimal amount of analyses and simulation during the development of Improved HAWK. As a result, in spite of increased simulation emphasis from 1970 on, there is not yet adequate capability to predict or to analyze flight problems; or to evaluate candidate solutions. This situation was compounded by the use of obsolescent telemetry, early omission of aeroelastic effects from simulations, and inadequate wind tunnel data.

C. PERFORMANCE NECESSITY

The requirement for the Improved HAWK (IH) system to engage the maneuvering target and the multiple target threat was discussed with representatives of the Missile Intelligence Agency (MIA); the Missile Command Laboratories; and the Applied Physics Laboratory (APL), Johns Hopkins University. All three agencies, although working independently, were generally consistent in their appraisal of the capabilities and vulnerability of the primary targets, the MIG 21 and other threat aircraft. MIA clearly demonstrated that the Army specified threat is consistent with current Soviet aircraft and pilot capabilities. APL data gathered in 1971 includes attack techniques against ground targets that would require IH to demonstrate high kill potential against multiple, high maneuver targets to ensure its own survivability. The profile of the "pop-up" target, the "vertical-S" evasive maneuver and the ability of the enemy to tailor attack formations to defeat specific air defense systems were described.

The capability of IH to engage the multiple and maneuvering attack models has been analyzed both through simulations and from extrapolation by AMSAA of the flight test results.

The "demonstrated" capability of IH was stated by the HAWK Project Office to be .31 and .28 against multiple (spacing 175 m) and maneuvering (single 6 g turn) respectively. These predictions are based on a small experimental sample and calculated warhead lethality. This capability, of course, is a significant increase over basic HAWK whose single shot kill probability under these target conditions would be approximately 5%.

There is little experimental data as to IH performance against maneuvering or multiple low altitude threats as only one of the 24 tests against maneuvering or multiple targets was conducted at an intercept altitude below 5000 feet above ground level.

Even if the Army could accept the statistical breakup probability in operational use, such occurrences do not appear to be acceptable in training exercises. It appears essential not only to exercise against multiple and maneuvering targets but also to control the missiles to avoid breakup during these exercises.

The following summarizes our observations with respect to the critical threat conditions and the deficiencies in current IH performance relative to these threats.

1) Closely Spaced Multiple Targets are a Realistic Threat

   a) They will degrade Improved HAWK performance except at close-in ranges.
   b) The calculated IH capability against multiple targets is undesirably low ($\approx .25$), considering missile life cycle costs, target numbers, and uncertainties in warhead effectiveness.
   c) Even if the break-up were avoided, miss distances are marginal and should be reduced particularly for longer range intercepts (greater than 20 Km).
   d) Close in resolution of multiple targets has not been demonstrated.

2) Hi-G Maneuvering Targets are a Realistic Threat

   a) They will degrade IH even if the break-up mechanism is avoided by forcing an increase in miss distance.

   b) The degradation will be most severe at high altitude vs high Mach No. targets. IH capability, however, is more important at intermediate altitudes down to the horizon. Degradation is also severe at longer slant ranges for intercepts after sustainer burnout.

   c) For a single maneuver the timing and target maneuver plane are critical. Ripple fire is a counter tactic.

   d) A continuous high g maneuver is also an observed threat from Soviet exercises and U.S. known capabilities. Ripple fire will not necessarily be effective against this tactic. The sustained maneuver will be lower in amplitude, e.g. typically 3 g for 15-20 seconds as contrasted with 6 g for 4 seconds.

D. PROBLEM ANALYSIS

There are a number of hypotheses as to the failure mechanism causing breakup. The principal ones advocated are roll control system saturation or structural failure. The roll system saturation derives from one or a combination of effects including rolling moments, roll-yaw-pitch coupling, aeroelastic effects, hinge moment effects or elevon limiting. Structural failure appears most probable in the wing or wing attachment points. There is no evidence that the breakup would be more or less prevalent at low altitudes than at the higher altitudes used in the tests.

The fixes evaluated since the problem first arose in the 1970-71 time period have all been in the nature of patchwork on the autopilot, no changes to the structure or aerodynamic configuration have been tested. There is probably no way that patching the autopilot can fully solve the problem in the sense of achieving both close to the full performance potential of IH and also avoiding breakup.

The Ad Hoc group has examined data from four major sources; flight tests, structural analysis, wind tunnel tests and simulations. Although none of these data sources establishes conclusively any single cause which initiates the breakup sequence, the committee believes that roll system saturation is the primary problem.

A brief summary of this review follows:

1) Flight Tests

Telemetry data from the seven flight tests which resulted in missile breakup were studied. Full telemetry consisting of autopilot/seeker commands, instrument outputs and elevon positions were available for multiple target flights 8006 and 275093, as well as the maneuvering target flight 275055. Pitch/yaw acceleration and front AGC were the only telemetry data available for multiple target flights 275023 and 275030 and maneuvering target flights 275026 and 275022. Position data were also determined from tracking camera film data. The film of flight 275093 and pictures of recovered flight hardware were also examined.

The following observations were reached from examination of the flight test data:

a) Pitch/yaw elevon radar commands saturated prior to missile breakup.
b) Elevon positions reached mechanical stops in wing plane maneuver.
c) Roll rate saturation immediately followed elevon position saturation.
d) Structural failure and missile breakup occurred after loss of roll control.
e) The differential deflection of the orthogonal elevons for roll control is too slow to effectively control the induced roll rate at high angles of attack.
f) The divergent limit cycle apparent in the telemetry data was corrected on flight #275093.

All the missiles appeared to be in a similar flight condition just prior to breakup. Either intentionally or due to erroneous cross-coupling of pitch and yaw commands, all missiles were maneuvering in or close to the plane of one pair of wings. All but one missile were flying at high Q; and all the high Q missiles showed evidence of a divergent body rate oscillation before loss of control. All missiles appeared to lose roll control effectiveness just prior to breakup.

2) Structural Analysis

The original IH missile wing design limit load was 14 g (12 ± 2) in the pitch and yaw planes with a vector resultant of 19.8 g maneuvering load in the plane of the wings. Overshoot was accounted for by adding a 30% factor resulting in a design limit of 25.7 g. The wing was designed to handle a worst case combination of g and elevon loads.

A detailed structural analysis of the IH wing and elevon was performed in 1971, utilizing loads data appropriate to the widened limits on commanded g's (20) and elevon deflections (22). These new loads were significantly larger than those to which the wing was originally designed. This structural analysis showed that many elements of the wing were computed to have negative ultimate margins of safety of -20 to -40%. Significantly, in addition to certain skin panel weaknesses, the wing aft attach bolt was shown to have the largest negative margin (under shear load). Full scale destructive tests of the wing in a Langley Wind Tunnel, where flight dynamic pressures and aerothermal heating can be simulated were performed early in 1971. In the tests carried beyond normal flight regimes to destruction, eight out of the ten wing failures occurred at the aft support.

Static deflection tests of the IH wing in 1971 have indicated the production wing is more flexible than the Basic HAWK honeycomb wing under the same loading conditions. Under the increased commanded g's of IH, the wings deflect approximately 2 inches at the tip. The effect of this deflection on elevon effectiveness (estimated to be a 20 to 40% reduction) and on induced rolling moments are very significant and have not been realistically accounted for in the dynamic simulations to date.

It is necessary to know whether these aeroelastic effects of the current IH wing are significant and if so, whether a simple change such as in increase in skin gauge will provide sufficient stiffness.

Even though the structural analysis indicated many areas of marginal design to the current IH load criteria, it is believed that the loads actually imposed in the breakup flights prior to loss of roll control did not exceed the structural capability. This does not obviate the possibility that wing attachment points could fail in disengagement rather than shear.

3) Wind Tunnel Testing

Wind tunnel tests on the HAWK aerodynamic configuration have been conducted since the mid 1950's. The initial tests were transonic and supersonic measuring forces, moments, and pressure distribution on one wing. They were run at roll angles of 0° and 45°. In 1968 additional tests were run to obtain data at higher angles of attack and to clarify elevon hinge moment data. In 1970, tests were run to provide additional data for simulation, induced rolling moment, and single panel deflections. After 1971, wind tunnel tests to explore potential flutter problems, demonstrate wing structural integrity, observe failure modes, and observe action of forward pin, there were still uncertainties in load distribtuions and in hinge moments. Further tests in 1972 addressed Reynolds number effects, loads, hinge moments for simulation and data. In April 1973, wind tunnel tests were run to obtain additional control effectiveness for simulation and additional wing gap data.

Wind tunnel data, until recently, have not been looking at bank angles other than zero and forty-five degrees. It therefore has not been possible to predict rolling moments caused by high angles of attack or missile aeroelastic effects.

In brief, the wind tunnel results are not conclusive in the problem identification.

4) Simulations

There are two types of simulations, one all digital and the other with a maximum of missile hardware in the loop on a 3 axis table responding to simulated RF signals. (The latter was used briefly in 1971-72 and is currently being reactivated).

The current state of the Raytheon digital simulation is that it is the major tool for study in optimization of the guidance and control system and for determining missile accuracy sensitivity to various threats. The simulation, however, is not sufficiently detailed to reproduce the combinations of events leading to breakups or to allow confident predictions of the effects of proposed design modifications.

The simulation has been limited from two aspects. First, until very recently, it has not accounted for certain basic phenomena such as roll, pitch, yaw coupling; and aeroelastic effects. Second, basic required input data, specifically aerodynamic, have not been available on a timely basis for use in the simulations.

Roll, pitch, yaw (RPY) coupling phenomena are characteristic of this type of aerodynamic wing-body configuration. These effects become more severe as the angle of attack is increased and become important at angles less than ten degrees. RPY coupling is introduced by induced rolling moments which roll the missile and thus successively change the pitching and yawing moments, calling for new trim elevon deflections that further change the rolling, pitching, and yawing moments. This situation progresses to oscillations that normally require judicious tightening of the roll autopilot loop and possibly of the longitudinal stability loops in order to reduce the response of the missile to "external" moments.

The simulation has been used for post flight analysis. It has been able to reproduce missile motions accurately except at the high angles of attack preceding loss of roll control.

The Ad Hoc group requested from Raytheon a simulation of IH performance with varying commanded g and elevon deflection limits against maneuvering and multiple targets.

Combinations studied were:

Combination	g	δ	
(20/22)	20	22°	(Current Improved HAWK)
(12/15)	12	15°	(Basic HAWK)
(20/15)	20	15°	

Based on examination of the maneuvering target cases analyzed, the degradation at 10K ft altitude or lower against the 4.8 g target for the (12/15) limit settings is significant only if the maneuver is required in a pure yaw or pitch plane six seconds or less before intercept. For high altitude intercepts of a maneuvering target (40K ft, 2.5 g) the degradation is significant over a wider time band.

The 20/15 combination showed very small degradations at 20K ft altitudes or lower when compared with the (20/22) combination.

Multiple target cases were simulated at altitudes of 10 to 18K ft and intercept ranges of 16 to 29 KM. No substantial differences in guidance accuracy were noted for the (12/15) limit settings as compared to the (20/22). In fact, in most cases the (20/22) missile showed larger miss distances due to overshoots. Overall the performance is driven by the time before intercept at which target resolution is firmly established and the guidance time constant.

E. POTENTIAL FIXES

The available fixes can be divided into three main categories: modifications already developed, or no risk; limit settings; and modifications suggested for development. These fixes and their probable effectiveness are discussed below.

1) Modifications Already Developed

We include in this category the elevon servo changes incorporated in the recent test missiles to alleviate the divergent limit cycle oscillations and the new design error multiplier. The present error multiplier is known to have excessive cross talk. The elevon servo modifications are specifically to reverse the elevon valve g sensitivity, to delete the elevon servo shaping network and to increase the roll autopilot band width. The Ad Hoc group believes that these modifications are good, and they will tend to reduce the probability that a missile will lose control, and are necessary but not sufficient elements of a fix to the breakup problem.

In the no risk category we include substituting a stronger and longer rear attachment point to the wing. Analyses have shown this attachment to be marginal in shear as well as to have tolerance buildups possible which could prevent full engagement of the bolt to the retaining nut. In addition, there is a possible (but probably not primary) failure if the wing and body flexure were sufficient to allow the bolt to pull out of the wing attachment.

2) Limit Settings

The elevon deflection commands and allowable "g" commands can be limited to 15° and 12 g respectively. These were the limits that the structure was designed to accommodate and these limits should allow much improved roll control capability. This change would be minor in nature and involves only some resistors in the autopilot.

In summary, these reduced limits will not significantly change the capability against multiple targets and, for the cases examined, there appeared to be acceptable degradation in capability against maneuvering targets - certainly less than the degradation resulting by breakup.

3) Modifications Requiring Development

There are a number of interrelated design changes that could significantly impact the missile performance. In the most part, however, their effects are interrelated. Principal categories are:

a) Autopilot Changes - The most important change would be to include selective limiting which has already been studied by Raytheon and the Army. The principle is to mix the pitch and yaw deflection commands and limit to a selected total elevon command allowing a reserve for roll control irrespective of the plane of maneuver. This modification was estimated by Raytheon to total approximately $2 million for development and retrofit. A second modification would be to increase the hydraulic pressure and thereby the resultant control torques. A minor increase (≈20%) would yield a marginal improvement whereas a major increase (e.g. doubling or tripling the pressure) would provide a major performance improvement but also would have major hardware implications.

b) Configuration Changes - Aerodynamic changes are desirable to reduce asymmetries which induce rolling moments and to reduce hinge moments. Hinge effects could be decreased by design and implementation of a "gapped" wing. The decrease would be under all maneuvering conditions while maintaining structural stiffness and integrity of the missile airframe and wings. This would be a complex change involving considerable wind tunnel testing and was estimated by Raytheon to cost approximately $20M for development and production change. There may be a simpler approach by clipping the current wings. This would still require a substantial investigative program before implementation.

c) Structural Changes - Stiffening the present wing would reduce aeroelastic effects and assist by reducing loss of elevon effectiveness due to wing bending and minimize possibility that unequal bendings would cause undesirable roll. A complete redesign of known marginal attachments should be considered.

F. RECOMMENDATIONS

1) The following modifications should be incorporated in both production line and fielded missiles prior to any further flight testing.

a) Reduce missile g limit and elevon deflection limit settings from current 20 g's and 22° in each plane to 12 g's and 15° respectively.
b) Incorporate the elevon servo modifications already tested.
c) Incorporate the new error multiplier.
d) Replace the present rear wing attachment bolt with a stronger and longer new bolt.

An initial group of 10 recent production missiles should be modified identically and flight tested to verify that these changes have, in fact, reduced the probability of breakup significantly. Test conditions should be primarily selected in the region where prior breakups have occurred and avoiding extreme environmental prelaunch conditions.

2) The selective limiting change should also be developed and incorporated in production missiles. When the selective limiting has been incorporated the g and δ limits should be reexamined. The selective limiting modification will require another series of proof flight tests.

3) Analytical, test, and simulation programs should be improved to provide an in depth understanding of the detailed mechanism of missile behavior and a tool to evaluate proposed modifications. The new wind tunnel data should be utilized.

4) The Army should determine, through a product improvement program, other modifications which, if incorporated, would permit maximum practical utilization of the inherent capability of Improved HAWK against specified targets and some expansion in its performance against higher performance targets.

The principal steps in this development program would be:

a) Selection of the best combination of control system, structural and/or configuration changes to achieve desired performance against critical target threats considering the time and cost to implement.

b) Verification of these modifications through extensive simulation and a subsequent flight test program (estimated 10-20 missiles).

This development program should not require longer than two years to complete. Total cost is estimated at between 10 to 20 million dollars.

G. SUMMARY

In summary, the probable cause of the April, 1973, IH missile breakup is loss of missile roll control when maneuvering in response to guidance commands. The condition should be corrected as the breakups or large misses affect both operational system performance and training for defense against multiple or maneuvering targets. Except for the breakup anomaly, Improved HAWK overall performance greatly exceeds that of Basic HAWK.

Implementation of the first recommendation will greatly reduce the probability of further breakups with tolerable performance degradation. This is the only high confidence course of action available to the Army at this time.

Implementation of the second recommendation would more than restore any performance loss resulting from the first recommendation.

Action on the third recommendation is necessary to assure that, if further problems develop, there will be in existence more effective tools for their solution.

Action on the fourth recommendation is desirable to ensure an option for important modifications in performance, within overall HAWK configuration constraints, against the evolving target threat.

R A Montgomery

R. A. Montgomery
Vice Chairman
Army Scientific Advisory Panel

DEPARTMENT OF THE ARMY
ARMY SCIENTIFIC ADVISORY PANEL
WASHINGTON, D.C. 20310

March 27, 1974

TO: General H. A. Miley, Jr.
Headquarters - Army Materiel Command
5001 Eisenhower Avenue
Alexandria, Virginia 22304

REFERENCE:

1. Letter from COL E. W. Deadwyler to Dr. R.A. Montgomery dated 25 February 1974

2. Memorandum from N. R. Augustine to General F. C. Weyand, dated 7 February 1974

3. Report by MICOM Aeroballistics Directorate, dated 6 February 1974, "Improved HAWK Missile Breakup Problem and Solution"

4. Report (2) Improved HAWK ASAP Ad Hoc Group, dated 7 September 1973

5. Improved HAWK ASAP Ad Hoc Group Report (1), dated 2 June 1973

Dear General Miley:

(C) SUMMARY:

(1) Fixes previously recommended appear adequate to avoid the breakup problem under most, if not all, operational conditions.

(2) The gapped wing configuration test results confirm alleviation of the hinge moment induced failure mode.

(3) Incorporation of ERCL is necessary to permit near-full utilization of the IH airframe g capability (20g), even with the gapped wing configuration. This is particularly important for low altitude intercepts.

(4) Incorporation of elevon deflection angle selective limiting (26^{o}) is strongly recommended as a prudent measure to minimize the probability of pitch roll yaw induced transients which can cause loss of lockon or, in the judgment of the panel, possible roll instability at high g and high angles of attack. This is an alternate failure mechanism.

(5) Substantial progress has been made since the last panel review (August 1973) by the Army and its contractors in gaining a fuller understanding of the breakup phenomena and in ability to reconcile flight test and simulation results.

(6) Mechanization of the recommended changes, although not studied in detail by the panel, appears to represent modest risk and also to represent minor increases in complexity and production cost.

(U) Reference 1 requested that the Improved HAWK Ad Hoc Group of the Army Scientific Advisory Panel reconvene for a one-day meeting. The meeting was held at Redstone Arsenal, Alabama on 6 March 1974. Panel members in attendance were R. A. Montgomery, Chairman, L. J. Delaney, A. R. Eaton, B. Reese and W. Ceely. The Ad Hoc Group was briefed by the HAWK Project Manager, the MICOM Laboratories, and the Raytheon Company.

(U) COL Deadwyler stated that the purpose of the meeting was to review (a) the results of the Improved HAWK Phase I modifications-validation program; (b) the Elevon Rate Command Limiter (ERCL) modification proposed by the Missile Command Laboratory; and (c) the approach being taken in Phase II of the program; and to obtain the comments and recommendations of the Ad Hoc Group.

(C) Because of the criticality of maneuver timing it appears that a salvo firing option could provide further improvement to the engagement kill performance of the Improved HAWK against maneuvering targets even after the planned modifications have been accomplished. The Ad Hoc Panel recommends further study on this.

(C) The flight test results for the six missiles incorporating the selective limiter; the modifications to the error multiplier, elevon servo, and the rear attach fitting; and with the g and δ limits set at 12 g's and 22° respectively are listed below:

Date Fired (1973)	Target/Plane	Miss Distance (ft)
12 November	Multiple/45°	6.7
16 November	Maneuver/0°	Reliability Failure
28 November	Multiple/0°	55
30 November	Maneuver/0°	19
10 December	Multiple/0°	24
14 December	Multiple/0°	50

These results indicate that the breakup problem is substantially avoided with this configuration (Phase I, ModA) and under the range of conditions tested. The miss distances achieved in flight were better than those expected from simulation.

(C) Three missiles were flown with the gapped wing modification.

Date Fired (1973)	Target/Plane	Miss Distance (ft)
26 October	Multiple/0°	Reliability Failure
9 November	Maneuver/45°	6.6
20 November	Multiple/0°	3.7

The first missile was a production prototype (1969), the second was an FY72 production missile, and the third was also an FY72 production missile modified as the missiles in the first table. Telemetry on the 9 November flight showed that the hinge moments for the gapped wing were significantly reduced for low elevon deflections compared to the standard wing, and were somewhat higher than predicted for the gapped wing. The trend of the data was as predicted over the range of elevon deflections measured (0-17 deg.), although the torque requirements at high values of elevon deflection are not yet determined.

(U) The Ad Hoc Group was briefed on the ERCL modification, Reference 3. The basic concept is to limit the commanded elevon deflection rate to values which can be achieved with the expected available actuator torque, thereby avoiding elevon rate saturation and the onset of a limit cycle. The commanded elevon deflection rate is limited by setting a limit on the difference between the commanded and actual airframe acceleration. This particular type of acceleration limit has been applied successfully on several missile programs.

(C) The committee was also briefed by the Contractor on simulation results which incorporated data on hinge moments and drag derived from the gapped wing flight test results, and a revised roll moment model based on the Rye Canyon wind tunnel tests. The attached figures indicate the relative improvement in performance calculated by Raytheon for several configurations under consideration. The calculations done to date show signficant improvement in high altitude performance by increasing the selective limit on the elevons to 26° and in low altitude performance by increasing the g limit to 20 g's. Further improvement at the higher altitudes can be achieved by going to non-selective limiting, assuming the roll control problem does not occur. Data was presented by Raytheon which showed the onset of control problems occurred when selective limiting at 28° was specified.

(C) The Ad Hoc Group concludes that the data obtained on the Phase I flight test program completed in December 1973 combined with the wind tunnel testing and simulation results represent a sufficient base from which to identify a preferred Improved HAWK configuration for development which can eliminate breakup without sacrificing performance.

Specifically, the following recommendations are made:

1. The modifications which are common to all the configurations discussed, namely, the new error multiplier, the elevon servo, and the rear attach fitting, should be incorporated in the preferred configuration.

2. The cut down Northrup gapped wing should be incorporated in the preferred configuration.

To assure a complete understanding of the aerodynamics of the revised gapped wing configuration the committee recommends continuation of the wind tunnel program to confirm the roll moment coefficients; to obtain hinge moment data at higher elevon deflections; and to examine the wing structural interactions more completely. The impact of the increased time of flight due to increased drag should also be assessed more fully for the longer range intercepts. Confirming flight test program to specifically include high Q (low altitude) flights against maneuvering targets to confirm the performance prediction for that regime.

3. The ERCL (elevon rate command limiter) should be incorporated in the preferred configuration.

The concept is well understood and has been widely applied, as noted previously. The specific implementation scheme for Improved HAWK was not evaluated by the panel; however, based on previous experience with the IH simulation, it is considered a moderate risk. ERCL incorporation is considered a necessary (though not sufficient) addition to IH to permit the maximum g capability of the airframe to be used. In general, it should be emphasized that the introduction of ERCL involves interaction with many aspects of dynamic performance that should be evaluated by further analyses and simulation. The panel considers there could be some degradation in miss distance against multiple targets under conditions of late resolution, although the data presented did not show this. However, the panel is convinced that benefit of properly selected ERCL scheme will greatly outweigh possible minor penalties.

Eight successful flight tests against four maneuvering and four multiple targets accompanied by extensive pre- and post-flight analysis are considered sufficient for incorporating ERCL into the production/retrofit program, assuming that the flight test results are in reasonable agreement with the analyses. The multiple target flights should include one at high altitude (12 km) and one at long range (30 km) to insure performance at the bounderies.

4. Selective limiting at $\pm 26^{\circ}$ and an acceleration limit of 20 g's should be incorporated in the preferred configuration.

The Ad Hoc Panel strongly recommends incorporation of selective limiting with the 20 g limit. The panel has previously identified loss of roll control due to PYR coupling at high angles of attack as a probable cause leading to breakup although it recognizes the Project recently has established strong evidence that the elevon hinge moments may be the primary cause. The actual cause, if there is a single cause, may never be identified with certainty. Incomplete wind tunnel data and aeroelastic understanding of the Improved HAWK airframe, and the additional effects of gapping the wing on aerodynamic performance represent uncertainties that must be provided for with additional margin in the roll control loop. Margin is also required to insure the system can handle flight conditions not yet investigated against more maneuverable and ECM capable targets. If the non- selective limited choice were made, leading to loss of roll control under "rare" conditions, the enemy would exploit that weakness and distort the expected average P_{ssk}.

(C) If the preferred configuration, Phase II-Mod B plus 26^{o} SL, encounters severe development problems during the flight test program, the Program Manager has available several alternate configurations which provide high assurance of avoiding recurrence of the breakup problem while retaining capability exceeding Basic HAWK, which performed well in the Yom Kippur war.

Richard A. Montgomery

R. A. Montgomery
Ad Hoc Group Chairman

0.5 P_{SSK} CONTOURS FOR $\Phi_A = 0$ deg (Per MN CDCCN 722803 1972, Random Timed
ESCAPE MANEUVERING TARGETS (Maneuver 2-10 secs before intercept.)
GAP WING, 10g ERCL, DLC', 20 g LIMIT

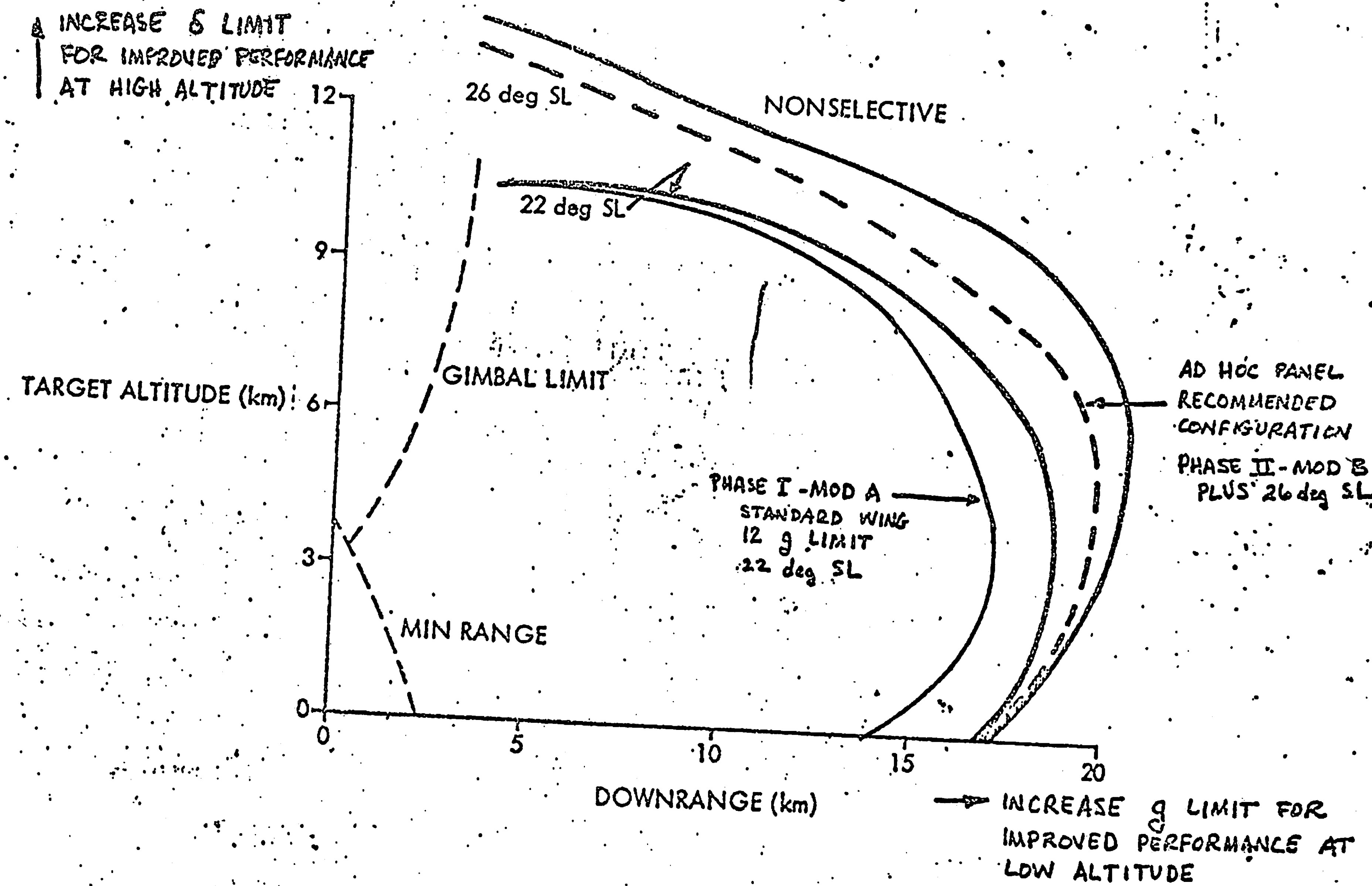

FIGURE 1

0.5 P_{SSK} CONTOURS - Φ_A = 0 deg MULTIPLE TARGETS (700 ft SEPARATION, V_T = 750 ft/sec) 26 deg SELECTIVE LIMITS, GAP WING, DLC', 10g ERCL, 20 g LIMIT

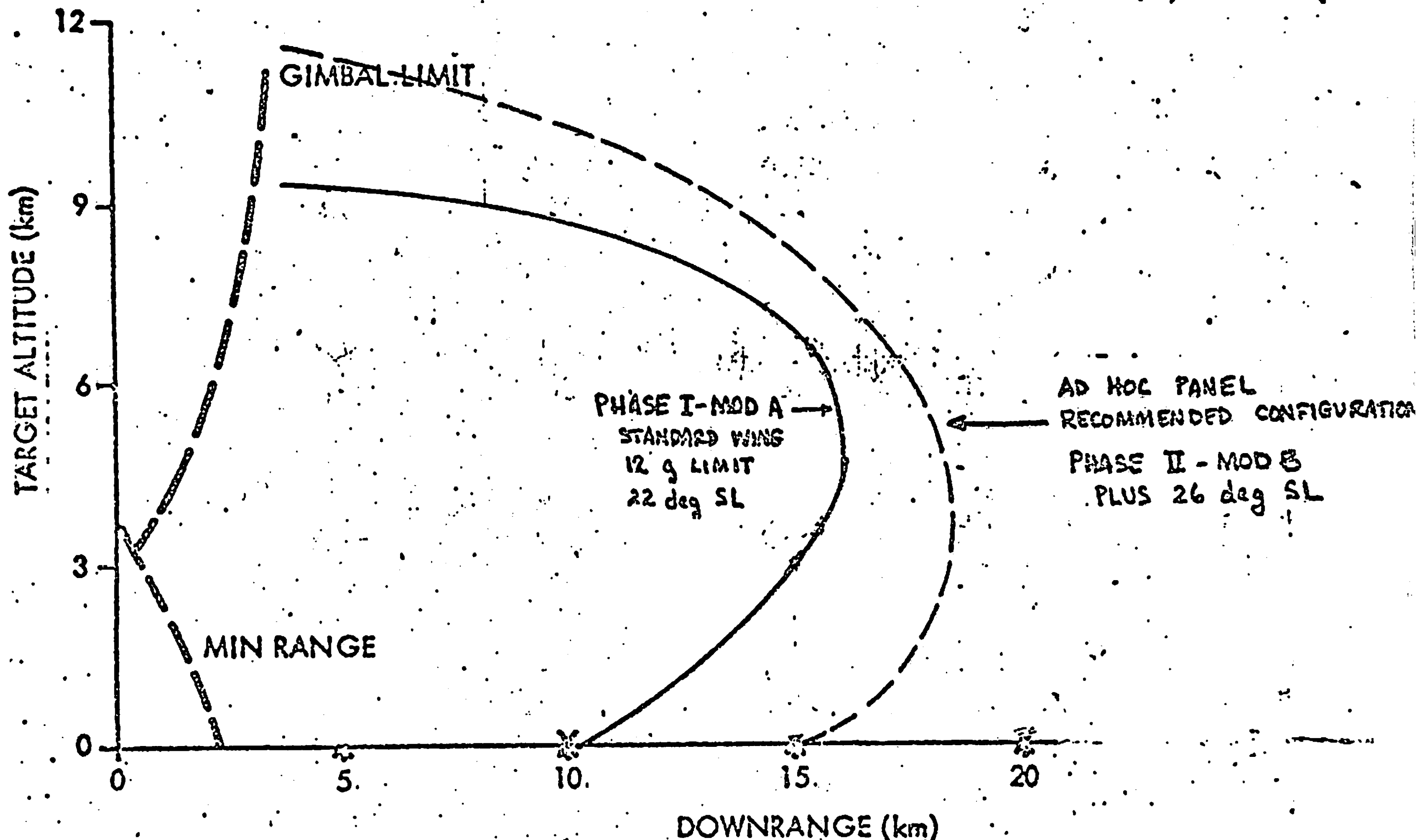

FIGURE 2

DISTRIBUTION LIST FOR ASAP AD HOC GROUP REPORT ON IMPROVED HAWK

DAFD - AD

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AVCSA

PM - IH (COL Deadwyler) - MICOM

Cdr, MICOM

EXCOM Members
- ASA(R&D)
- Cdr, USAMC
- Cdr, USTRADOC
- CRD
- DASA(R&D)
- Mr. Lawrence O'Neill
- Dr. Richard A. Montgomery

Ad Hoc Group Members
- Dr. Richard A. Montgomery, Chairman
- Mr. Daniel Fink
- Dr. Bruce Reese
- Dr. Larry Delaney
- Mr. Al R. Eaton
- Mr. John W. Thomas

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BOEING AEROSPACE COMPANY
SEATTLE, WASHINGTON 98124

R. A. MONTGOMERY

September 7, 1973

General H. A. Miley, Jr.
Headquarters - Army Materiel Command
5001 Eisenhauer Avenue
Alexandria, Virginia 22304

Dear Hank:

Per our telephone discussion, I am enclosing a draft copy of our supplementary report on Improved Hawk. I have conveyed the contents of this report today to Col. Deadwyler.

I will hold sending you the original until I hear any comments from you or your office.

Sincerely,

Dick

R. A. Montgomery

Enclosure

IF ENCLOSURES ARE WITHDRAWN (OR NOT ATTACHED) THE CLASSIFICATION OF THIS CORRESPONDENCE WILL BE CANCELLED.

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DRAFT

BOEING AEROSPACE COMPANY

P.O. Box 3999 Seattle, Washington 98124

2-1020-0000-125
September 7, 1973

To: General H. A. Miley, Jr.
Headquarters - Army Materiel Command
5001 Eisenhauer Avenue
Alexandria, Virginia 22304

Reference: 2 June Improved Hawk ASAP Ad Hoc Group Report (U)

Dear General Miley:

(U) Per your request, the ASAP Improved Hawk Ad Hoc Group met on August 30th at the Missile Command Headquarters in Huntsville to review the status of the Improved Hawk Modification and Test Program. The Ad Hoc Group was briefed by the Hawk Project Office (Col. Deadwyler), by the MICOM Laboratories, and by representatives of the Raytheon Company, the prime contractor.

(U) As stated by Col. Deadwyler, the purposes of the meeting were to: (a) review possible changes in direction on the modification program; (b) to consider the problem causes; (c) to clarify the Ad Hoc Group's recommendations on the selective limiter modification; and (d) to recommend retention, deletion, or revisions to the current modification program.

(U) The Project Office and the contractor reviewed the current status of the modifications being implemented and the rationale for those modifications that went beyond the ASAP Ad Hoc Group's 2nd June recommendations. The specific additional modifications being implemented are: a roll autopilot bandwidth increase; a seeker head pressure increas; and a elevon servo pressure increase.

(C) The contractor also reviewed the difficulties experienced in the first two flights of the recommended 10 missile program (#345168 and #345170). Both of these flights had experienced saturation roll rate disturbances early in the flight. The roll caused loss of guidance lock for both missiles. The first missile recovered from the roll, reacquired and homed on the target, but with an excessive guidance error believed to be due to an intermittent AGC ground. The second missile did not recover lock after the roll disturbance. Little progress had been made in identifying the specific cause of the incidents.

(U) The committee was also briefed on the recent MICOM analysis of the breakup phenomenon. This is now attributed to increases in elevon hinge moments which occur due to elevon and/or wing bending and resultant roll torques. Simulation results were presented which predict loss of roll control under combinations of elevon angles, angle of attack, and g's experienced in prior flights which broke up. There were also additional data presented as to the effect of wing gapping on reducing the elevon hinge moment buildup.

(U) Significant progress has been made in the past few months in improving the simulations and in understanding the mechanisms which caused breakups in prior flights.

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DECLASSIFIED ON DECEMBER 31, 1975

(C) In view of the current status of the program and the progress in technical understanding, the Ad Hoc Group makes the following recommendations:

1. The Army should continue the test program with modifications as contained in Recommendations 1 and 2 of Section F of the 2 June report. Other modifications should be deleted from the existing 8 modified missiles. G and δ limits should be set at 12g and 22° respectively in the selective limiter. These modifications should be incorporated in production missiles after verification by the test program.

   In the view of the Ad Hoc Group, these modifications and limits should greatly reduce the probability of further breakups through avoidance of extreme flight conditions. The missile tested successfully on June 6, 1973 incorporated these changes except for the selective limiter (#275089).

2. After assurance that breakup incidents can be avoided or greatly reduced, per Recommendation 1, and considering the new understanding of the failure mechanism and the improved simulations results, a package of specific product improvements already designed should be flight tested in a second group of 8-10 missiles. These are (a) the seeker head pressure increase; (b) the roll autopilot bandwidth modification; and (c) the cut down Northrup wing to provide gapping without wing relocation. This package of modifications would be additive to those implemented under Recommendation 1 above.

(U) The Ad Hoc Group believes that these three additional modifications, if carefully implemented and with adequate preflight simulations, would both correct the basic cause of loss of roll control and provide significantly improved performance, increasing the utility of the system against specified targets and providing some expansion in capability against higher performance targets. This program should proceed even if full scale wind tunnel testing cannot be accomplished in time to support it.

(U) This program could now be accomplished much more expeditiously and economically than the program recommended (Recommendation 4) of the 2 June report. Early and successful completion of this product improvement program would make available to the Army the option to incorporate these important product improvements in production missiles.

BOEING AEROSPACE COMPANY
(A division of The Boeing Company)

R. A. Montgomery
Ad Hoc Group Chairman

cc: Ad Hoc Group Members:

D. Fink (not present)
J. Thomas
L. Delaney
A. Eaton
B. Reese
Col. A. N. Champion
Col. D. Walsh
Col. E. W. Deadwyler

DEPARTMENT OF THE ARMY
ARMY SCIENTIFIC ADVISORY PANEL
Washington, D. C. 20310

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for

AD HOC GROUP
on

3 May 1973

Improved Hawk

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