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NO. 1135

DEVELOPMENT OF AN RPV AND DRONE REAL-TIME SIMULATION FACILITY: FEASIBILITY REPORT (U)

by

A.B. Markov

PCN 031SE

November 1986

DEFENCE RESEARCH ESTABLISHMENT SUFFIELD, RALSTON, ALBERTA

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ABSTRACT

18

//This report presents the results of the feasibility study for a DRES real-time RPV and drone simulation facility (SIMFAC). The report includes a review of existing hardware/software assets, a review of design and interface requirements, a cost/benefit analysis, a first generation development program and definition and comparison of three proposed zeroth generation configurations that could satisfy some near-term requirements.//

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

LIST OF TABLES (cont'd)

LIST OF FIGURES

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DEVELOPMENT OF AN RPV AND DRONE REAL-TIME SIMULATION FACILITY: FEASIBILITY REPORT (U)

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1. INTRODUCTION

Development of a Remotely Piloted Vehicle (RPV) and drone real-time simulation facility (SIMFAC) was first considered at DRES in CY1983. This facility, in its ultimate form, would provide a capability for real time debugging and evaluation of autopilot software and hardware, for RPV pilot training without risk to expensive airframes and on-board equipment, and for a simulation system that could be used in developing and evaluating operational procedures.

The initial discussions were motivated by a growing recognition of the need for a real-time software development tool for ROBOT-X flight software. This rocket-boosted aerial target, currently undergoing flight test at DRES (Figure 1), is a "fire-and-forget" drone controlled by a microprocessor-based autopilot system, and has over 10,000 assembler level lines of code as its airborne subset. Flight qualification of this software was and continues to be a significant task and would have been considerably aided by a SIMFAC capability.

The internal discussions in 1983 crystalized into a proposed SIMFAC development program that was circulated within DRES in January, 1984. The proposed program was separated into three phases as follows:

a) Phase 1 - Feasibility Assessment.
b) Phase 2 - First Generation SIMFAC Development.
c) Phase 3 - Advanced SIMFAC Development.

The feasibility assessment was conducted internally at DRES. This assessment took place as prototype ROBOT-X autopilot hardware and software became available; with this many of the concerns and problems anticipated in the earlier SIMFAC discussions became real, and provided a direct incentive and rationale for SIMFAC development.

The feasibility study was completed early in 1985, and strongly recommended acquisition of a SIMFAC capability with at the very least having a capability to support drone autopilot "processor-in-the-loop" simulation. The feasibility study is described in this report. It includes the following:

a) A detailed assessment of the need for a SIMFAC facility including a cost/benefit analysis (Section 2).
b) A detailed examination of design and interface requirements for a first generation SIMFAC facility (Section 3).
c) A first generation SIMFAC development program (Section 4) including estimated capital costs and R&D contractor support requirements.
d) A comparison of three proposed "strawman" configurations, including two "zeroth" generation configurations intended to partially fulfill near-term requirements.

2. SIMFAC REQUIREMENT - A DETAILED ASSESSMENT

The Systems Section of the Defence Research Establishment Suffield (DRES) is extensively involved in the design, development, test and evaluation of unmanned aerial systems in support of Canadian Forces (CF) requirements. Current systems under development and undergoing flight test include ROBOT-X (Figure 1) and the HULK (Figure 2). Other configurations under consideration include R^2P^2 (Figure 3), a canard pusher propeller configuration and ROBOT-LRX, a supersonic rocket boosted target.

All of these systems make use of advanced, microprocessor based autopilots that require the definition and debugging of a suitable software subset. These autopilots interface with an assortment of sensors that vary from vehicle to vehicle and from mission to mission. As well, interfaces are required for control servos, for downlink telemetry and for uplink command and control systems.

The missions for these unmanned aerial systems include aerial target roles (e.g. ROBOT-X) and nontarget roles (e.g. HULK) such as surveillance, direction of artillery fire, target designation and harassment roles.

The roles of SIMFAC in the development of such a varied assortment of RPV's and drones and associated ground systems must also be quite diverse. They are discussed in more detail in the following sections.

2.1 Development, Test and Evaluation of Autopilot Software

In this role SIMFAC would simulate the airframe dynamics which the autopilot would "fly", as illustrated in the block diagram of Figure 4. This would allow substantially complete debugging of autopilot software without the risk of catastrophic failures caused by software problems. It is particularly important to proper development of true drone configurations in which a reversion to an RPV mode is not available as a failsafe.

To date, in the development of RPV's at DRES, the availability of a manual reversion mode has allowed debugging of the autopilot software in a series of test flights that permit changes of control law gains as the flight progresses and reversion to the manual mode if the autopilot loses control. This approach has proven to be satisfactory in HULK development.

2.4 Evaluation of New RPV and Drone Configurations

In this role the emphasis is not on the human or automatic pilot end but on evaluating the simulated flight characteristics of unproven drone and RPV configurations. It would take advantage of the simulation capability inherent in a SIMFAC facility and would allow the user to conduct studies examining the controlability and handling qualities of proposed designs, in some cases in concert with the autopilots that are intended for the airframe. The utility of such a role is largely dependent on the accuracy to which the aerodynamic characteristics of the airframe are known.

The latter is always a problem in preliminary air vehicle design. It is being addressed at DRES with the development of in-house aerodynamic prediction software, with the purchase/rental of existing software and data bases, and with wind tunnel testing conducted in cooperation with the National Aeronautical Establishment. This growing capability allows for the definition of reasonably accurate aerodynamic models that can then be used in SIMFAC. As is common practice in the field, aerodynamic uncertainties are taken into account with appropriate sensitivity analyses.

2.5 Post Mortem Simulation

In certain cases, use of SIMFAC to simulate accidents and/or incidents could provide useful insight into the causes of a real flight problem. The latter could include modeling prevailing wind conditions and simulating sensor, interface and other autopilot failures that are postulated to have been the cause of the problem in an attempt to reproduce the problem. This technique is commonly used in investigating manned aircraft accidents and has proven its utility many times.

2.6 Flight Ground Station

In certain missions, a properly configured SIMFAC facility could also be used as a ground station for actual flights. This would generally require only a subset of the facility, e.g. in ROBOT-X flights SIMFAC could be used as a ground station computer interfacing with the autopilot.

2.7 SIMFAC Limitations

While the previous six subsections identify the primary roles in which a SIMFAC facility would be useful, it is not the intention of this report to suggest that such a facility would eliminate the need for all other ground tests, but rather that it is a complementary development tool. SIMFAC is ideally configured for designing and testing man/machine interfaces, sensor interfaces, autopilot software and operating procedures. It cannot, without operation in conjunction with other equipment, test equipment environmentally or in operation under realistic flight vibration and load environments. Furthermore, it does not test the actual flight sensors, radios and associated antennas.

Thus the need for a combined subsystem test program complementary to SIMFAC testing continues, including, but not restricted to, the following:

a) Structural testing.
b) Environmental testing.
c) Rate table and g-table testing.
d) Calibration of sensors.
e) Antenna pattern tests.
f) Airborne subsystem captive flight tests.
g) Motion facility testing.

2.8 Cost/Benefit Analysis

In the development and testing of unmanned aerial systems one may philosophically approach flight testing from two fundamentally different points of view:

a) Flight testing with minimal **a priori** ground testing and minimal airborne instrumentation.

b) Flight testing preceded by a comprehensive series of ground tests followed by tests of fully instrumented airborne systems.

The former approach is substantially captured by the cliché "test by trial and error", but can be quite effective if the airborne systems are relatively low cost and if some ground based instrumentation is used (e.g. video/cine/radar tracking). It has been used successfully in the development and test of ROBOT-9.

The second, comprehensive approach is essential if complex and costly airborne systems, for which only limited test systems exist, are to be qualified.

The implementation of SIMFAC can reasonably be justified only for the complex systems for which comprehensive ground tests are required. Once implemented, however, it will be available for both classes.

The cost/benefit considerations are most rationally separated into drone systems (e.g. ROBOT-X) and RPV systems (e.g. HULK). Table 1 provides rough cost estimates, in first flight test configurations, of ROBOT-X and HULK. The former is assumed to have a full suite of telemetry equipment and associated instrumentation, in particular a telemetry transmitter and a 64 channel PCM encoder. The latter is assumed to be in a common RPV first flight configuration, i.e. little or no on-board telemetry and no autopilot or special sensors, suitable for a short range flight directly in the control of the pilot.

These costs are strictly hardware replacement costs and do not include the manpower resources required to integrate a replacement system. Such costs may be substantial as can be indirect costs resulting from program delays (e.g. confidence in the viability of a program and loss of potential off-shore markets).

ROBOT-X cost considerations also include the following:

a) In proof-of-concept (POC) flight testing, only ten airframes are available. Given that the resources available for the POC flight test program will allow, at most, eighteen flights of one to five minute duration, all flights are important and premature termination of any flight, even with a successful recovery, will result in loss of valuable test data.

b) Even in the event of premature flight termination via a successful, commanded recovery system deployment, ROBOT-7R (Ref. 1) and ROBOT-X test results suggest that airframe damage in some circumstances could be substantial and will not always allow quick turn around of the same airframe (although the avionics will survive and could be readily transferred to a different airframe).

c) Given the costs indicated in Table 1, it is apparent that only a small number of catastrophic flight failures resulting in the total loss of the airborne system could be tolerated without significant increase in development costs, and significant delays in the development program.

For these reasons, ROBOT-X development leading up to flight test placed a heavy emphasis on the flight qualification of the recovery system. Largely due to a lack of manpower resources and real-time hardware in-the-loop simulation capability, less emphasis was placed on autopilot software qualification with the full recognition that this was likely to lead to premature termination of at least four or five flights, particularly early, critical flights in the POC test program. The latter estimate was based largely on experience in the development of flight software of some complexity, but is justified more rigorously in the remainder of this section using a realiability analysis and, indirectly, through the experience acquired in the first three ROBOT-X flights. In virtually all drone and RPV development programs known to the author (e.g. the NASA HiMAT RPV, Ref. 2) extensive **real-time** simulation was used to debug the software. It should be noted that six degree-of-freedom DRES software, while debugging the form and logic of the ROBOT-X flight software, does not emulate the translation of the software into the form to be used in the autopilot microprocessor nor does it emulate any of the numerous hardware interface and timing considerations of the real autopilot.

It is also worth noting that in older, analog autopilots (e.g. the Canadair CL-89 drone development, Ref. 3), real-time simulation was facilitated through the use of analog computer simulation in conjunction with an analog autopilot.

Hardware-in-the-loop simulation techniques are also well established in manned aircraft development (e.g. the Sea Harrier, the Tornado and the JA37 Viggen, Refs. 4 to 7).

2.8.1 ROBOT-X Failure Analysis

The analysis in this section was developed in support of the SIMFAC feasibility study. It was completed prior to the first ROBOT-X flight, and thus does not include actual flight data. The results of this analysis, however, are not inconsistent with what has been observed in the first three flights.

To quantify the cost/benefit ratio of SIMFAC development in the ROBOT-X context, an estimate is required of the success/failure probabilities of key ROBOT-X systems in proof-of-concept flight testing. The latter are clearly difficult to estimate accurately **a priori**, but some useful conservative numbers may be inferred based on past experience with similar systems, on the results of subsystem flight trials (e.g. ROBOT-7R flight tests of the recovery system, Ref. 1) and on the results of subsystem static tests (e.g. subsystem performance under simulated environmental and load conditions).

For the purpose of this simplified analysis, the key probability relationships are given below. The probability $(P_{PD})_{GCR}$ of successful parachute deployment following a ground commanded recovery is

$$(P_{PD})_{GCR} = n_P n_C n_{GCR} \tag{2.1}$$

or

$$(P_{PD})_{GCR} = n_P n_C n_{CR} n_{TLM} n_{MC} n_h \qquad (2.2)$$

Here n_{GCR} represents the overall reliability of those elements of ground commanded recovery independent of autopilot commanded recovery, i.e.

$$n_{GCR} = n_{CR} n_{TLM} n_{MC} n_h \qquad (2.3)$$

where n_P is the probability of a successful parachute system deployment given that the hatch and aft-lug bolt firing commands are generated, n_C is the probability of the serviceability of the Command Recovery and Integrated Staging and Ignition System (CRISIS) electronics, n_{CR} is the probability of the successful transmission and reception of the ground recovery command, n_{TLM} is the probability of telemetry system performance to sufficient quality and presentation of real-time information that will allow ground controllers to identify a potentially catastrophic problem and initiate commanded recovery procedures, n_{MC} is the probability that ground controllers will recognize and respond correctly to a potentially catastrophic problem, and n_h is the probability that such a problem will be recognized at an altitude and vehicle configuration that will make recovery feasible.

Similarily, one may define a probability $(P_{PD})_{ACR}$ of successful parachute deployment following an autopilot commanded recovery as

$$(P_{PD})_{ACR} = n_P n_C n_{ACR} \qquad (2.4)$$

where n_P and n_C are as defined for equation (2.1) and n_{ACR} is the probability that a given ROBOT-X flight will end in the autopilot successfully generating a parachute deployment command.

n_{ACR} is, in fact, an expression of the flight reliability of ROBOT-X in POC flight testing. It includes the contributions of all subsystems, i.e. control servos (n_S), the autopilot electronics (n_{APE}), autopilot sensors (n_{APS}), autopilot software (n_{APSO}), airframe structure (n_{AF}), rocket motors (n_{RM}) and battery power supplies (n_{PS}). Thus we may write

$$n_{ACR} = n_S n_{APE}\, n_{APS}\, n_{APSO}\, n_{AF}\, n_{RM}\, n_{PS} \tag{2.5}$$

or, substituting for n_{ACR} in equation (2.4),

$$(p_{PD})_{ACR} = n_P n_C n_S n_{APE} n_{APS} n_{APSO} n_{AF} n_{RM} n_{PS} \tag{2.6}$$

The probability of a successful parachute deployment P_{PD} regardless of whether it is autopilot or ground commanded is given by

$$P_{PD} = n_P n_C \lfloor n_{GCR} + n_{ACR}(1 - n_{GCR})\rfloor \tag{2.7}$$

or

$$P_{PD} = n_P n_C \lfloor n_{CR} n_{TLM} n_{MC} n_h + n_S n_{APE} n_{APS} n_{APSO} n_{AF} n_{RM} n_{PS}(1 - n_{CR} n_{TLM} n_{MC} n_h)\rfloor \tag{2.8}$$

where it has been assumed that all the component probabilities are mutually independent and that ground communicated recovery will not be attempted if autopilot commanded recovery is obtained and is successful.

Table 2 gives estimates of the subsystem probabilites of equation (2.8) assuming that SIMFAC is not available or not used.

Based on the data of Table 2 and equations (2.2), (2.6) and (2.8) the probability of successful parachute deployment in proof-of-concept flight tests has been computed and the results summarized in Table 3.

For early POC flights, the results suggest relatively pessimistic results, with the overall probability P_{PD} of successful parachute deployment being only 0.52, i.e. only slightly more than one half of early flights will be successfully recovered. The probability $(P_{PD})_{ACR}$ of a successful autopilot commanded recovery is only 0.26, i.e. only slightly more than one quarter of early test flights will end in an autopilot commanded recovery. Since an autopilot commanded recovery implies a successful execution of the mission profile, it is the **de facto** probability of a successful first flight!

These probabilities improve considerably for later POC test flights in which one may reasonably assume a steep learning curve in the operation of and marked improvement in the performance of key subsystems. The exact form of this improvement is unknown, although it is not unreasonable to assume that a large part will occur in the first half of the approximately eighteen POC test flights planned.

For the purpose of the argument to be put forward here, it is adequate and conservative to assume that the late POC probabilities will be achieved after half of the POC flights have been completed, i.e. after ten flights. The probabilities over these first ten flights, averaged assuming a linear learning curve, are seen to be

$$(P_{PD})_{ACR} = 0.50,$$

$$(P_{PD})_{GCR} = 0.53,$$

and

$$P_{PD} = 0.71$$

These results imply, among other things, the possibility of the total loss of several airborne systems due to unsuccessful recovery resulting in the catastrophic destruction of the vehicle. This may be expressed more completely and formally in terms of the probability that a successful recovery will occur r times in the first ten flights, $r \triangledown 10$.

From probability theory (Ref. 8), this may be done using the binomial law, i.e. if the probability of occurrence of an event in a single trial is P, then the probability that it will occur exactly r times in n independent trials is

$$P_r = \left\lfloor \frac{n!}{r!(n-r)!} \right\rfloor P^r(1 - P)^{n-r} \qquad (2.9)$$

Based on equation (2.9), Table 4 summarizes the resulting probabilities. In this table, $(P_{PD})_{\geqslant r}$ represents the probability that a successful recovery will occur r or more times in the first ten flights, i.e. (Ref. 8)

$$(P_{PD})_{\geqslant r} = \sum_{i=n-r}^{n} (P_{PD})_i \qquad (2.10)$$

Table 4 suggests that the most likely outcome is seven successfully recovered flights and that more than 70% of the outcomes lead to six, seven, or eight successful parachute deployments. The probability of other outcomes falls off rapidly. In particular, there is a very low probability of ten successful parachute deployments (0.033) and a relatively low probability of nine or more successful parachute deployments (0.166), i.e. it is quite probable that at least two of the first ten POC flights will end with the total loss of the airborne system.

It is emphasized that while two catastrophic failures are not particularly satisfactory outcomes, this possibility has been taken into account in ROBOT-X POC test plans and can be sustained without terminating the test program, and without requiring additional development funds.

These calculations were made based on reliability data for key subsystems prepared without the use of SIMFAC. The calculations must be repeated for reliability data postulated with the use of SIMFAC.

In examining Table 2, it is clear that two areas strongly and adversely affect the probability of successful deployment, i.e. the autopilot software reliability (n_{APSO}) and the mission controller reliability (n_{MC}). Both these areas are particularly amenable to improvement with even simple configurations of SIMFAC, i.e. this facility would allow more reliable debugging of the autopilot software **using actual autopilot software and electronics and operating in real time** and would allow repeated training of mission controlers to give them real-time exposure to the data being presented and interpreted, training for dealing with foreseeable abort scenarios, and training for familiarization with the expected mission profile on a given flight, thus allowing them to more readily identify abnormal flight situations.

Having stated these major benefits qualitatively, it is far more difficult to make a quantitative statement. Rather, in Table 5 the affected parameters are presented using optimistic, likely and pessimistic values. While n_{MC} and n_{APSO} are the main beneficiaries of the availability and use of SIMFAC, CRISIS reliability (n_C) and telemetry system reliability (n_{TLM}) also benefit tangibly as both have software/hardware that can operate simultaneously with SIMFAC simulations and may thus be thoroughly checked out and debugged.

The lower half of Table 5 summarizes the resultant probabilities of successful parachute deployments. Even using a pessimistic analysis, in early POC test flights the probability of successful parachute deployment goes up 13% from 0.52 to 0.65. This is a very tangible benefit; it is emphasized that it is **likely** to be more.

Assuming, conservatively, as before, that the late POC test flight probabilities will be achieved after ten flights, then uniformly averaged probabilities over the first ten flights may be computed, as summarized in Table 6. The data of Table 6 have been used to generate the probabilities that successful recoveries will result r times in the first ten flights, as summarized in Table 7. Cumulative probabilities are given in Table 8.

Tables 7 and 8 also show that use of SIMFAC produces a significant improvement. For example, the probability of having ten successful parachute deployments is almost three times greater, even with a pessimistic analysis (it is five times greater with the optimistic analysis).

Viewed somewhat differently, Table 7 indicates that the most probable outcomes are seven successful parachute deployments without SIMFAC and eight or nine with SIMFAC.

Finally, viewed cumulatively, the probability of **nine or ten** successful parachute deployments without SIMFAC is 0.16 while it is between 0.35 (pessimistic) and 0.5 (optimistic) with SIMFAC. Other cumulative probabilities are also summarized in Table 8.

2.8.2 Cost/Benefit Summary

Based on the results of the previous section and assuming that the SIMFAC data conservatively brackets the possible outcomes, then it is reasonable to conclude that the use of SIMFAC would likely prevent **at least one** catastrophic ROBOT-X failure. Benefits after the first ten flights are not as dramatic, but would also be significant over the whole of POC and advanced development testing. The psychological advantage of a far reduced likelihood of consecutive catastrophic failures is also very important but is difficult to quantify.

From Table 1, one airframe represents a saving of $180K just in hardware replacement cost alone, not including manpower costs incurred in assessing a flight failure and preparing a follow-on airframe. As will be shown in the following sections, this on its own is sufficient to justify and complete the development of substantial SIMFAC capability. In reality, based on cost/benefit considerations, two to three times that amount could be justified on **ROBOT-X grounds alone.**

ROBOT-X would hardly be the sole beneficiary of SIMFAC. A similar analysis may be performed for RPV systems. Such an analysis would have to take into account the presence of the RPV pilot. Because of the "fail-safe" aspect of the presence of an RPV pilot, the benefits would not be as dramatic as for drone configurations. In the longer term, however, they are likely to be significant. This is particularly true for high value systems, as might be the case for airframes with increasingly sophisticated and costly sensor platforms and for configurations with unusual flight characteristics for which SIMFAC-based RPV pilot training would be especially beneficial and for which extensive autopilot software ground testing is essential.

SIMFAC capability, once implemented, would be available as a design and development tool for all RPV and drone work carried out at DRES in support of CF requirements in the next ten to fifteen years. Such programs may include, but are not restricted to, upcoming long endurance RPV development and a medium range, low altitude supersonic target drone.

Finally, this capability could also be made available to Canadian industry. Follow-on programs to the Canadair CL-289 reconnaissance drone and the CL-227 battlefield surveillance RPV are two potential industrial beneficiaries.

3. SIMFAC DESIGN AND INTERFACE REQUIREMENTS

The previous section has presented a cost/benefit justification for the implementation of SIMFAC capability. In this section design and interface requirements are analyzed in more detail in an effort to present a summary of possible requirements for zeroth and first generation capability that would allow technical staff to acquire hands-on experience with SIMFAC and thus more rationally define requirements for a fully capable second generation system. A zeroth generation SIMFAC would also provide a "quick and dirty" capability that could be of significant near-term benefit to on-going airborne system development, most notably ROBOT-X.

3.1 Design Requirements and Constraints

3.1.1 Schedule

The most immediate and beneficial impact of SIMFAC will be in ROBOT-X development. Consequently, SIMFAC development should take place as quickly as possible.

3.1.2 Cost

In Section 2 it was shown that it was not difficult to justify $180K for the development of SIMFAC based solely on ROBOT-X considerations. In terms of all of the RPV and drone programs, the actual benefits are far more ($500K plus) and thus it would not be unreasonable to budget a level of effort of $150-200K for capital and R&D contractor support in the development of a first generation capability.

3.1.3 Capability

A first generation system would ideally have the following general capabilities:

a) It would be able to support real-time six degree-of-freedom simulation using **simplified** vehicle dynamics and aerodynamic models.
b) It would have the capability for interfacing with the Atlantis ROBOT-X autopilot and the DRES PEGASUS autopilot.
c) It would have the capability for interfacing with the ROBOT-X telemetry system, thus allowing for the training of mission controllers.
d) It would have the capability for interfacing with the RPV command and control ground station.

3.1.4 Software

A first generation system would make use of available software wherever possible. In particular, it would make use of the following DRES controlled and/or developed software:

a) Simplified versions of ROBOT-X six degree-of-freedom simulation software modified to improve execution efficiency, thus permitting real-time execution, and modified to remove elements that would not require simulation (e.g. control logic and algorithm software as this would now be available in the real autopilot). This software is also readily adaptable to propeller RPV configurations.
b) RPV command and control system pilot's display station software.

3.1.5 Hardware

A first generation system would make use of as much available and accessible DRES hardware as possible. In particular, use of the following computer systems, currently available at DRES, should be investigated either as peripheral systems to SIMFAC in conjunction with other, purchased hardware, or as core computers:

a) The Flight Instrumentation Laboratory IBM PC-XT.
b) The telemetry data acquisition PDP11-34.
c) The Honeywell DPS-6 and DPS-8/70C computers.

The VAX11/780, considered a good core computer for SIMFAC in the program originally proposed in 1983 has been ruled out as it is largely dedicated to Ordnance Detection Group data acquisition tasks and is not available.

It would be highly desirable that any purchased hardware be available for other tasks (e.g. the ROBOT-X ground station requirement and other SIG scientific computing and data acquisition requirements).

Hardware used in the RPV command and control system pilot's display and control station would be interfaced with SIMFAC when RPV configurations are being used.

3.1.6 Location

In order to make use of available space and hardware resources, the best location for SIMFAC is in the Building 15 Test Complex at DRES. This would provide for SIMFAC proximity to a number of key systems and areas including the following:

a) The RPV command and control ground station.
b) The telemetry ground station.
c) The telemetry data acquisition computer and associated peripherals.
d) The Flight Instrumentation Laboratory.
e) The main RPV and drone system integration and assembly areas including the RPV Flight System Integration Laboratory and the ROBOT Flight System Integration Laboratory.

3.1.7 Miscellaneous

A first generation system, while likely to be limited in its capabilities, should be configured in a way that provides a good data and experience foundation for any second generation work. Modularity in both hardware and software is highly desirable.

3.2 Interface Requirements

A first generation SIMFAC facility **could** be capable of interfacing with the following DRES equipment and facilities:

a) ROBOT-X autopilot - SIMFAC interfacing capability is required to accept autopilot generated servo commands (pulse width and analog), autopilot generated engine ignition commands and autopilot generated parachute deployment commands and to simulate autopilot sensor inputs.

b) PEGASUS - SIMFAC interfacing capability is required to accept autopilot generated pulse width servo commands, to communicate through serial and discrete parallel digital ports and to simulate autopilot sensor inputs.

c) RPV Command and Control Base Station - SIMFAC interfacing capability is required to simulate RPV downlink data (e.g. pilot's display station parameters such as altitude, airspeed, engine RPM and so forth) and accept RPV uplink data (e.g. the pilot's control commands).

d) Telemetry Base Station - SIMFAC interfacing capability is required to simulate a telemetry data stream.

These interface requirements are stated generally for completeness. They imply a significant capability in a first generation system and are not necessarily achievable given reasonable schedule and cost constraints. Prioritization and requirements reduction are considered in detail in Section 4.

Tables 9 and 10 define, respectively, the detailed interface requirements corresponding to items (a) and (b).

The ROBOT-X autopilot interface requirements presented in Table 9 include a number of sensors that are only candidate sensors that are currently being evaluated, and may or may not be used in POC test flights. They are included for completeness and provide a representative sampling of the simulated sensor outputs that SIMFAC could be required to generate both for the ROBOT-X autopilot and for PEGASUS.

The sensor temperature interfaces are required in order to simulate the output of temperature sensors located in the autopilot sensor enclosures and used to correct temperature sensitive response through autopilot software correction factors.

In order to conduct a real-time simulation, SIMFAC must know when a rocket motor stage firing has been commanded. Thus Table 9 provides data suitable for defining an interface either at the autopilot output end to CRISIS or at the

CRISIS output end. The latter is preferable in that it more fully exercises the ROBOT-X avionics. More detailed ROBOT-X autopilot interface requirements are given in Ref. 9.

The Pegasus interface requirements of Table 10 include sensor input characteristics generically. Representative sensor characteristics are as for those of ROBOT-X in Table 9.

The RPV Command and Control base station may be included directly in SIMFAC by implementing the uplink/downlink interfaces between the autopilot and its downlink transmitter and the autopilot and its uplink receiver, as indicated in Figure 5, thereby **requiring no alteration of the ground station or its software and exercising the complete command and control system.** The actual link between the downlink and the uplink transmitter/receiver pairs may be hardwired for convenience. The autopilot remains as part of the simulation and is thus also exercised.

The alternative to this is to have SIMFAC simulate the autopilot dynamics and downlink data stream and accept the ground station uplink command stream in a suitable format, thereby by-passing the need for the autopilot and uplink/downlink transmitter/receiver pairs to be part of the simulation. While this is not as comprehensive a simulation, it may be necessary under some circumstances (e.g. if autopilot hardware and/or software is not available). The SIMFAC block diagram for this configuration is given in Figure 7.

The telemetry base station, analogously to the RPV command and control base station, may be included in SIMFAC by implementating the telemetry downlink interface between the autopilot and its downlink transmitter, as indicated in Figure 6, **thereby requiring no alteration to the telemetry ground station or its software and still exercising the complete system.** The actual link between the telemetry encoder/decoder (or transmitter/receiver) may be hardwired for convenience. The autopilot remains part of the simulation and is thus also exercised.

As for the RPV command and control base station, this approach may not always be possible. If so, a direct link to the telemetry base station from SIMFAC will be required. In this mode SIMFAC would be required to generate a simulated PCM data stream that is realistic and may be input into the telemetry base station. These data could be generated to represent possible faults encountered in flight, including failure of selected data channels leading to misleading mission controller information and data representing actual vehicle anomalous behavior of varying degrees of severity. The SIMFAC block diagram for this configuration is given in Figure 8. The specific SIMFAC interface requirements will depend on the data format in the PCM stream.

4. PROPOSED PHASE 2 SIMFAC DEVELOPMENT PROGRAM

This section describes in detail a proposed Phase 2 SIMFAC development program leading to a first generation capability. As indicated in the previous section, the intent of a first generation system is both to provide a near-term capability to reduce some of the significant risks associated with test flights in RPV and drone development and to provide a good basis for any second generation work.

The tasks associated with this program are summarized in the following sections. The tasks are keyed by phase, thus Task 1 of Phase 2 will be Task 2.1 and so forth. The tasks are not intended to be conducted serially; many can and should proceed in parallel in the interest of an efficient development program.

4.1 Task 2.1 - Review of the Proposed Phase 2 Development Program and Commitment of Resources

The main objective of this task is to conduct an internal review of the recommendations of this report and to firmly establish the level of effort and resources required and available for continued SIMFAC development. This task has been completed.

4.2 Task 2.2 - Development and Implementation of Zeroth Generation Capability

As indicated in Section 2, the lack of any DRES SIMFAC capability reduces ROBOT-X POC test flight reliability. In order to partially remedy this situation, it is proposed that action be taken to implement a **"zeroth"** generation capability as per one of the "straw-man" configurations proposed in Section 5. While it was initially proposed that this be done under R&D contract, it is now being done as an in-house activity, in part in response to the urgency of the requirement.

4.3 Task 2.3 - First Generation SIMFAC Development RFP

A request for proposal (RFP) was prepared and a first generation SIMFAC R&D contract awarded after a competitive offering to qualified Canadian companies. The winning company, Atlantis Flight Research Inc., is now initiating development work as per the following tasks under the R&D contract of Ref. 10.

4.4 Task 2.4 - First Generation SIMFAC Development R&D Contract

In close cooperation with DRES staff and drawing upon available DRES facilities, test data, hardware and software, the successful contractor will conduct a first generation SIMFAC development, including implementation, as per the following tasks.

4.4.1 Task 2.4.1 - Detailed Review of Requirements and Constraints

The contractor will conduct a detailed review of first generation SIMFAC design and interface requirements, design constraints, available DRES facilities and available DRES hardware and software. This review will require, as output, a definition of what the maximum capability is, given firm cost and schedule constraints.

The review, of necessity, must concentrate on the critical areas of computational demand and input/output capability and speed.

4.4.2 Task 2.4.2 - Definition of a First Generation SIMFAC Configuration

Based on the results of the review of Task 2.4.1, the contractor will define, in detail, a proposed first generation SIMFAC configuration. This configuration will optimize use of available DRES hardware and software resources and off-the-shelf hardware and software and will make use of custom designed hardware and software only when dictated by availability or cost constraints.

4.4.3 Task 2.4.3 - Implementation of a First Generation Configuration

After a DRES go no-go decision, the contractor, in close co-operation with DRES staff, will procure and/or develop the necessary hardware and software and will system integrate and implement a first generation SIMFAC capability at DRES.

4.4.4 Task 2.4.4 - Operational Demonstration of a First Generation Configuration

In close co-operation with DRES staff, the contractor will demonstrate the successful operation of SIMFAC including demonstration of all of the capabilities defined as feasible in the review of Task 2.4.1.

4.4.5 Task 2.4.5 - Documentation

The contractor will fully document all of the work conducted throughout the tasks of the contract including engineering and construction drawings, detailed system description, detailed description of custom designed software and hardware, complete operating and maintenance procedures and complete user software documentation.

4.5 Task 2.5 - Review of First Generation SIMFAC Capabilities

DRES will review the operating capabilities and limitations of the first generation SIMFAC and discuss development of a second generation system with the contractor. In considering whether to proceed with second generation development, the following questions must be answered:

a) Does the scope (current and future) of DRES RPV and drone programs warrant second generation development?

b) Are there potential benefits to Canadian industry (e.g. industry use of SIMFAC)?

c) Are the first generation capabilities adequate for the majority of DRES applications, i.e. has the first generation capability already advanced SIMFAC to the point of diminishing returns making the cost/benefit ratio of further development unattractive?

4.6 Cost Estimate for First Generation SIMFAC Development

Judicious allocation of available resources, tailoring of design requirements to the resources available and firm constraints on the resources available to contractors should provide a sound basis for a first generation SIMFAC development in the $150-200K range for total capital and R&D contract expenditures.

4.7 Proposed Schedule

The effective commencement date for the first generation SIMFAC R&D contract of Ref. 10 was 10 August, 1986. Based on this date, a first generation SIMFAC capability at DRES will be fully commisioned by August, 1987.

5. ZEROTH GENERATION SIMFAC DEVELOPMENT

In Section 4.2, as a consequence of the SIMFAC feasibility study it was recommended that consideration be given to implementing a "zeroth" generation capability that would serve as a bridge between having no SIMFAC capability and having first generation capability. To be most useful, this capability would include real-time simulation for the mission controllers and simultaneous, multiple sensor open-loop simulation for the ROBOT-X autopilot.

Both of these capabilities have been or are currently being addressed. The mission controller training capability was implemented prior to the first ROBOT-X flight through the development of real-time graphics software for simulating controller displays. This simulation, presented on Tektronix 4105 or 4107 graphics terminals, is based on nominal and off-nominal six degree-of-freedom simulations generated off-line using DRES 6 DOF software. The resulting software package, named MICONSIM, is currently resident on the DRES VAX11/780 computer and has been successfully applied in ROBOT-X mission controller training prior to all flights.

The open-loop sensor simulation capability is currently being implemented around an IBM PC XT available in the Flight Instrumentation Laboratory. Except for the host PC, it completely parallels the first "strawman" configuration resulting from the SIMFAC feasibility study (see Section 5.1 to follow). A different computer was used in order to make use of an available system, and thus reduce cost. This capability is expected to be available late in CY1986.

The following three subsections describe three "strawman" zeroth-generation configurations that were formulated as part of the SIMFAC feasibility study. The first one is the only true zeroth generation system in that it is low-cost (less than $50K) and has very limited capability for real-time vehicle dynamic simulation. The third configuration is more expensive and is in fact an example of a system that could be considered a "strawman" first generation system.

The configurations were formulated in CY1984 and early 1985, when the feasibility study was conducted, and provide a representative comparison of low, medium and high performance systems available at the time. No attempt has been made to update the hardware specification in order to preserve the specific recommendations of the feasibility study, and the context in which they were made. A quick review of currently available systems has indicated that this in no way alters the recommendations of the original feasibility study.

5.1 Zeroth Generation SIMFAC - Configuration 1

The first configuration has been developed around a Compaq Plus portable personal computer in conjunction with a number of Tecmar peripherals and accessories. The configuration is described in more detail in Table 11.

The highlights of this configuration include the following:

a) The Compaq Plus is IBM software compatible and will thus be able to use software already availalbe at DRES plus numerous other software packages being marketed for the IBM XT.

b) With an RS232 serial interface it is a portable, self-contained ROBOT-X ground station suitable for an advanced version of the current ground station, with its limited capabilities, developed around an HP85 minicomputer.

c) It is the lowest priced of the three configurations proposed.

d) It is configured around the Compaq Plus compatible Tecmar Lab Master interface, which with 4 Tecmar DADIO boards provides 16 single-ended or 8 independent D/A converters, all with 12 bit resolution.

e) The latter also provides a significant laboratory data acquisition capability at minimal cost.

5.2 Zeroth Generation SIMFAC - Configuration 2

The second configuration has been developed around a Hewlett Packard (HP) Integral personal computer in conjunction with a number of HP peripherals and accessories. The configuration is described in more detail in Table 12.

The highlights of this configuration include the following:

a) The system can interface with all HP peripherals and accessories compatible with the Hewlett-Packard interface bus (HP-IB, IEEE-488), including items which are currently available at DRES.

b) The system has a large HP software base. Some HP software is currently available at DRES.

c) As for the Compaq Plus, with an RS 232C serial interface it is a portable, self-contained ROBOT-X ground station suitable for an advanced version of the current ground station.

d) It is configured around high quality HP A/D (8) and D/A (18) interfaces. The possibility of augmenting these interfaces with additional equipment already available at DRES (e.g. the HP3497A data acquisition/control unit) at minimal cost exists.

e) The latter provides additional high quality laboratory data acquisition capability supplementing available DRES capability.

5.3 Zeroth Generation SIMFAC - Configuration 3

The third configuration has been developed around a Masscomp MC-500 series system. The configuration is described in more detail in Table 13.

The highlights of this configuration include the following:

a) The RTU-01 UNIX based real-time operating system.

b) A single 32-bit virtual memory CPU with system architecture suitable for adding a parallel second CPU if required.

c) A 12-bit, 16 channel, 1 MHz programmable gain A/D.

d) A single/double precision floating point processor.

e) The system provides additional high quality laboratory data acquisition capability supplementing available DRES capability.

f) Fortran 77 is available making DRES Fortran six degree-of-freedom simulation software directly compatible.

5.4 Telemetry PCM Data Stream Simulation

An important element of a first generation SIMFAC is the capability for generating a telemetry data stream simulating the data downlink to the telemetry ground station. The latter allows for hardware and software telemetry ground station debugging and, as importantly, exposure of the mission controllers to realistic real-time data with possible simulated ground station and airborne system faults.

The most convenient and non-intrusive (to the telemetry ground station) method of doing this is to generate a PCM data stream in a format identical to the real data stream (see also the discussion in Section 3.2).

5.5 Comparison of the Proposed Configurations

Table 14 compares the main features of the three proposed configurations. In making comparisons, it is emphasized that the three configurations presented were chosen not only for the attributes they possess suitable for SIMFAC use but also as examples of the broad spectrum of configuration performance and cost that are available. They are representative but not exhaustive. They are not equivalent in performance.

The highlights of Table 14 include the following:

a) All three configurations satisfy the zeroth and first generation channel requirements for A/D and D/A interfaces. The Compaq configuration interfaces are slow and of the lowest quality.
b) Both the Compaq Plus and the HP configurations are built around portable computers that with one RS232C serial interface could conveniently be used as part of advanced ROBOT-X ground stations.
c) Only the Masscomp configuraton is a true 32-bit system. This in combination with the FP-501 array processor makes it the only configuration, of the three proposed, capable of comprehensive real-time six degree-of-freedom simulation.
d) With regard to the real-time simulation described in the previous item, the Compaq configuration is very limited and may not be able to do even rudimentary 6 DOF simulation, i.e. it may be capable of only exercising selected autopilot channels using pre-defined time histories. The

latter capability, however, could still be quite valuable (e.g see the comments in Ref. 2).

e) All three configurations provide a significant increase in available A/D and D/A capability that could augment current Systems Integration Group capabilities, particularly as required for structural testing. The HP configuration would augment and be compatible with HP data acquisition equipment currently available at DRES.

f) At under \$20K the Compaq configuration is by far the lowest priced (Configuration 2 is \$64K and Configuration 3 is \$81K), entirely configured from hardware and software developed for the personal computer and small business markets.

g) The HP configuration is a mixture of a relatively low cost personal computer with high quality, expensive D/A and A/D interfaces. Its major limitation is that the HP Integral personal computer does not have the architecture required for a significant six degree-of-freedom real-time simulation capability. Thus this configuration suffers from an analogous deficiency to that described for the Compaq configuration in item (d) at a price that is only marginally acceptable for a zeroth generation configuration.

h) The Masscomp configuration is the most expensive and, as might be expected, the best-suited for the real-time simulation required. It significantly exceeds the zeroth generation cost guidelines outlined and is in fact most appropriately treated as a candidate first generation system.

5.6 Zeroth Generation SIMFAC Recommendations

Based on the results of the zeroth generation configuration study, it was recommended that immediate priority be given to the following:

a) Implementation of mission controller training capability.

b) Implementation of autopilot sensor simulation capability as per strawman configuration 1.

As has already been indicated recommendation (a) has already been implemented, while recommendation (b) is currently being actioned.

6. SUMMARY AND FUTURE WORK

The results of an in-house feasibility study for a real-time RPV and drone simulation facility (SIMFAC) have been presented. This review completes Phase 1 of the SIMFAC development program and has included a detailed summary of requirements, a detailed cost/benefit analysis developed around ROBOT-X, a summary RPV cost/benefit discussion and the definition of a detailed Phase 2 development program including zeroth and first generation development. A zeroth generation configuration was proposed in response to compelling ROBOT-X considerations and thus a number of zeroth generation configuration alternatives were considered in-depth and compared. The zeroth and first generation recommendations of the study are currently being implemented.

The ROBOT-X success/failure analysis has rigorously confirmed POC test plans that call for ten airframes and five complete avionics systems and has identified a number of potential problem areas indicating the need for special care and attention. This analysis and the recommendations of the feasibility study have been also supported by ROBOT-X flight test experience acquired to date.

In part due to the recommendations of the feasibility study and the identification of a number of software development deficiencies, a number of steps have been taken to minimize ROBOT-X software problems:

a) Extensive software and sensor interface ground and manned aircraft tests.
b) Simplified mission profiles in early flights.
c) Structured, modular software developed to clearly stated specifications.
d) Extensive nonreal-time six degree-of-freedom simulation.
e) Stimulation of autopilot sensor channels with open-loop signals.

f) Extensive autopilot mode and sensor failure analysis.

g) Mission controller training.

These steps allow uninterrupted ROBOT-X development in parallel with SIMFAC development.

As a result of this study, R&D contract action has been initiated for Phase 2 SIMFAC development with a $165K commitment. The cost/benefit ratio of such a development is extremely favourable. The successful implementation of a first generation capability would provide the basis for a simulation facility serving RPV and drone research and development needs over the next ten to fifteen years. Evolutionary development to a second generation system could then take place if and when improvements in capability are required.

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TABLE 1 EQUIPMENT REPLACEMENT COST ESTIMATES FOR ROBOT-X AND HULK

DESCRIPTION	COST ($000)	REMARKS
ROBOT-X:		
1. AUTOPILOT	8	Includes autopilot battery power supply.
2. AUTOPILOT SENSORS	16	Does not include flight test instrumentation.
3. ROCKET IGNITION AND STAGING SYSTEM	2	Includes CRISIS and RISER modules.
4. GROUND COMMANDED RECOVERY RECEIVER AND ANTENNA	7.5	
5. SERVO ACTUATORS	15	
6. TELEMETRY SYSTEM	70	Includes telemetry transmitter, PCM encoder, autopilot/PCM encoder interface, instrumentation, signal conditioning, flight test boom, battery power supply.
7. AIRFRAME	60	
ROBOT-X TOTAL	178.5	
HULK:		
1. COMMAND AND CONTROL AVIONICS	40	Includes uplink command receiver and servo interface electronics.
2. STEERABLE TV CAMERA	18	
3. AIRFRAME INCLUDING SERVOS	15	
HULK TOTAL	73	

NOTES:
(i) Costs are strictly equipment replacement costs in low volume, prototype form.
(ii) HULK is assumed to carry limited instrumentation, i.e., it is in a "typical" RPV first flight configuration.
(iii) Development costs are not included.

TABLE 2 ROBOT-X SUBSYSTEM PROOF-OF-CONCEPT FLIGHT TEST RELIABILITY ESTIMATES: SIMFAC NOT AVAILABLE OR NOT USED

ITEM	DESCRIPTION	EARLY POC TEST FLIGHT RELIABILITY	LATE POC TEST FLIGHT RELIABILITY	REMARKS
n_P	Parachute system reliability	0.97	0.97	• Based on ROBOT-7R firings and on prior experience with similar systems.
n_C	CRISIS reliability	0.95	0.99	• Based on ROBOT-7R firings, and on ground environmental and load tests.
n_{CR}	Ground command T_X/R_X reliability	0.8	0.95	• Based on ROBOT-7R firings, use of mil-spec command T_X/R_X, and on past experience with similar systems.
n_{TLM}	Telemetry system reliability	0.85	0.95	• The assumption has been made that mission rules will call for flight termination as soon as the telemetry data stream is lost for more than a short period of time (say for 5 seconds).
n_{MC}	Mission reliability	0.60	0.85	• This is likely to be one of the "weak links" in reliability, particularly in early flights.
n_h	Probability that vehicle is at minimum parachute deployment altitude.	0.95	0.95	• It is assumed that POC flight profiles will be planned for high, safe altitudes.
n_S	Servo reliability	0.99	0.99	• High performance, high reliability servos.
n_{APE}	Autopilot electronics reliability	0.9	0.97	• Based on ground tests to be done plus general experience with reliability of prototype electronics.

TABLE 2 ROBOT-X SUBSYSTEM PROOF-OF-CONCEPT FLIGHT TEST RELIABILITY ESTIMATES: SIMFAC NOT AVAILABLE OR NOT USED (cont'd)

ITEM	DESCRIPTION	EARLY POC TEST FLIGHT RELIABILITY	LATE POC TEST FLIGHT RELIABILITY	REMARKS
n_{APS}	Autopilot sensors reliability	0.8	0.95	• Based on experience to date plus successful outcome of ground tests.
n_{APSO}	Autopilot software reliability	0.5	0.90	• Steep learning curve is assumed based on experience in complex software development.
n_{AF}	Airframe reliability	0.9	0.97	• Based on on-going static structural tests. • Assumption made that flight envelope will be explored to its limits.
n_{RM}	CRV-7 reliability	0.99	0.99	• Based on past experience. • Assumption made that asymmetric motor firing will be catastrophic.
n_{PS}	Battery power supply reliability	0.90	0.98	• Based on assumption of thorough ground testing and past experience with reliability of battery systems.

TABLE 3 ROBOT-X PROOF-OF-CONCEPT FLIGHT TEST RECOVERY PROBABILITIES: SIMFAC NOT AVAILABLE OR NOT USED

ITEM	DESCRIPTION	EARLY POC TEST FLIGHT RELIABILITY	LATE POC TEST FLIGHT RELIABILITY
$(P_{PD})_{ACR}$	Probability of a successful autopilot commanded parachute deployment.	0.26	0.74
$(P_{PD})_{GCR}$	Probability of a successful ground commanded parachute deployment.	0.36	0.70
P_{PD}	Total probability of a successful parachute deployment either by ground command or by autopilot command.	0.52	0.90

TABLE 4 PROBABILITY OF SUCCESSFUL PARACHUTE DEPLOYMENT ON r OF THE FIRST TEN ROBOT-X POC TEST FLIGHTS: SIMFAC NOT AVAILABLE OR NOT USED*

r	$(P_{PD})_r$	$(P_{PD})_{\geq r}$
0	0.0000042	1.00
1	0.00010	0.9996
2	0.0011	0.9995
3	0.0074	0.998
4	0.032	0.991
5	0.093	0.959
6	0.19	0.866
7	0.27	0.676
8	0.24	0.406
9	0.13	0.166
10	0.033	0.033

*NOTE: $P_{PD} = 0.71$ (see text, Section 2.8)

TABLE 5 ROBOT-X SUBSYSTEM RELIABILITY DATA: ITEMS INFLUENCED BY USE OF SIMFAC

ITEM	DESCRIPTION	EARLY POC TEST FLIGHT RELIABILITY				LATE POC TEST FLIGHT RELIABILITY			
		WITHOUT SIMFAC	WITH SIMFAC			WITHOUT SIMFAC	WITH SIMFAC		
			Optimistic	Likely	Pessimistic		Optimistic	Likely	Pessimistic
n_C	CRISIS reliability	0.95	0.98	0.97	0.95	0.99	0.99	0.99	0.99
n_{TLM}	Telemetry System Reliability	0.85	0.90	0.87	0.85	0.95	0.97	0.96	0.95
n_{MC}	Reliability of Mission Controllers	0.60	0.80	0.75	0.70	0.85	0.95	0.92	0.90
n_{APSO}	Autopilot Software Reliability	0.50	0.90	0.85	0.80	0.90	0.99	0.95	0.93
$(P_{PD})_{ACR}$	Probability of a successful autopilot commanded parachute deployment	0.26	0.49	0.46	0.42	0.74	0.82	0.78	0.77
$(P_{PD})_{GCR}$	Probability of a successful ground commanded parachute deployment	0.36	0.52	0.47	0.42	0.70	0.80	0.77	0.74
P_{PD}	Total probability of a successful parachute deployment either by ground command or by autopilot command	0.52	0.74	0.70	0.65	0.90	0.94	0.92	0.92

TABLE 6 ROBOT-X UNIFORMLY AVERAGED PROBABILITY OF SUCCESSFUL PARACHUTE DEPLOYMENT DURING THE FIRST TEN POC TEST FLIGHTS

DESCRIPTION	$(P_{PD})_{ACR}$	$(P_{PD})_{GCR}$	P_{PD}
WITHOUT SIMFAC	0.50	0.53	0.71
WITH SIMFAC:			
OPTIMISTIC	0.66	0.66	0.84
LIKELY	0.62	0.62	0.81
PESSIMISTIC	0.60	0.58	0.79

TABLE 7 PROBABILITY OF SUCCESSFUL PARACHUTE DEPLOYMENT ON r OF THE FIRST TEN ROBOT-X POC TEST FLIGHTS*

r	$(P_{PD})_r$			
	WITHOUT SIMFAC	WITH SIMFAC		
		OPTIMISTIC	LIKELY	PESSIMISTIC
0	0.0000042	1.1×10^{-8}	6.1×10^{-8}	1.7×10^{-7}
1	0.00010	5.8×10^{-7}	2.6×10^{-6}	6.3×10^{-6}
2	0.0011	0.000014	0.000050	0.00011
3	0.0074	0.00019	0.00057	0.0011
4	0.032	0.0018	0.0043	0.0070
5	0.093	0.011	0.022	0.032
6	0.19	0.048	0.077	0.099
7	0.27	0.15	0.19	0.21
8	0.24	0.29	0.30	0.30
9	0.13	0.33	0.29	0.25
10	0.033	0.17	0.12	0.095

*NOTE: Based on P_{PD} values of Table 6, as follows:

$P_{PD} = 0.71$ without SIMFAC

$P_{PD} = 0.84$ with SIMFAC (optimistic)

$P_{PD} = 0.81$ with SIMFAC (likely)

$P_{PD} = 0.79$ with SIMFAC (pessimistic)

TABLE 8 CUMULATIVE PROBABILITY OF SUCCESSFUL PARACHUTE DEPLOYMENT ON r OR MORE OF THE FIRST TEN ROBOT-X POC TEST FLIGHTS*

r	$(P_{PD})_{\geq r}$			
	WITHOUT SIMFAC	WITH SIMFAC		
		OPTIMISTIC	LIKELY	PESSIMISTIC
6	0.87	0.99	0.98	0.95
7	0.68	0.94	0.90	0.86
8	0.41	0.79	0.71	0.65
9	0.17	0.50	0.41	0.35
10	0.033	0.17	0.12	0.095

*NOTE: Based on the data of Table 7.

TABLE 9 ROBOT-X AUTOPILOT SIMFAC INTERFACE REQUIREMENTS

ITEM	NO. ITEMS (NO INTERFACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT* OUTPUT/INPUT (NOMINAL)	REMARKS
SERVO COMMANDS				
● Analog	4 (4)	A/D	0-5V	Up to 4 independent analog proportional servo commands output from autopilot and digitized for input into SIMFAC as airframe control commands.
● Pulse Width	8 (8)	A/D	0-5V 1-4ms TTL	Up to 8 independent PW proportional servo commands output from autopilot and digitized for input into SIMFAC as airframe control commands.
CRISIS COMMANDS (from Autopilot)				
● Pin OUT 1 of 8254	1 (1)	A/D	0-5V	8-12 ms pulse - engine fire command. 18-22 ms pulse - drogue chute deploy command. 28-32 ms pulse - main chute deploy. In general requirement may exist for SIMFAC interface at the autopilot CRISIS commands end or, more realistically, at the CRISIS/RISER output end.
● Pin OUT 2 of 8254	1 (1)	A/D	0-5V	Low line indicates autopilot processor fail.
CRISIS OUTPUT				
● To RISER	1 (2)	A/D	0-28 VDC	Rotary switch step line. Rocket motor fire line. Current will depend on actual impedance and capacitor voltage.

TABLE 9 ROBOT-X AUTOPILOT SIMFAC INTERFACE REQUIREMENTS (cont'd)

ITEM	NO. ITEMS (NO INTER-FACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT* OUTPUT/INPUT (NOMINAL)	REMARKS
CRISIS OUTPUT (cont'd)				
• To hatch explosive bolts.	1 (1)	A/D	0-28 VDC	As above.
• To aft explosive bolts.	1 (1)	A/D	0-28 VDC	As above.
AUTOPILOT DIGITAL INTERFACES				
• Ground Station	1 (1)	D/D	RS232C or 422	Autopilot/ground station interface.
• PCM Downlink	1 (1)	D/D	TTL level, 16 bit, unidirectional parallel interface with handshaking.	
SENSORS				
• Absolute pressure transducer	1 (2)	D/A	@ 9V power supply for pres; 0-9V for temp diode.	Kavlico P655-15A-A2A (0-15 psi). Input to autopilot A/D sensor interface. Temp sensor part of pressure transducer.
• Differential pressure transducer	1 (2)	D/A	@ 9V power supply; 2-6V supply for pres; 0-9V for temp diode.	Kavlico P656-11D-A2A (0-10 psi). Input to autopilot A/D sensor interface. Temp sensor part of pressure transducer.
• Magnetometer	1 (3)	D/A	0-5 VDC per axis; 2.7 kΩ output impedence.	Develco 9200C three-axis (3) magnetometer, ± 600 milligauss per axis. Three independent SIMFAC outputs required representing each axis.

TABLE 9 ROBOT-X AUTOPILOT SIMFAC INTERFACE REQUIREMENTS (cont'd)

ITEM	NO. ITEMS (NO INTER-FACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT* OUTPUT/INPUT (NOMINAL)	REMARKS
SENSORS (cont'd)				
● Magnetomer temp sensor	1 (1)	D/A	As appropriate to magnetometer range.	For correcting magnetometer temp sensitive characteristics.
● Radar Altimeter	1 (1)	D/A	0.08-10 V +4mV/ft 19±2VDC off-scale, load capability: 1K Ohm minimum.	King KRA-10A radar altimeter.
● Homing System 1	1 (2)	D/A	DC sine and cosine 4.5V ±3.0V (150mA max).	King KR87 ADF Two SIMFAC outputs required representing sine and cosine of bearing angle.
● Homing System 2		D/A	TACAN VOR Composite, .5VRMS 0 Degree Phase and Serial BCD data bus.	King KTU709 TACAN, will not be used in POC ROBOT-X tests.
● Accelerometers	3 (3)	D/A	-45mA to 45mA	Sundstrand QA 800 servo accelerometer (±15g).
● Accelerometer temp sensor	1 (1)	D/A	As appropriate to accelerometer environment.	For correction accel. temp sensitive characteristics.
● Rate sensors 1	3 (3)	D/A	±3VDC	Smiths 902-RGS-3 rate gyros (±100°/sec). Smiths rate gyros may not be used on all ROBOT-X POC test flights.
● Rate sensors 2	1 (3)	D/A	0 to + 5VDC	Humphrey RT02-0201-1 electro-fluidic angular rate sensor ±60°/sec pitch. ±360°/sec roll, ±60°/sec yaw. One of several alternative rate sensors that will be evaluated and may be flown on ROBOT-X POC test flights.

TABLE 9 ROBOT-X AUTOPILOT SIMFAC INTERFACE REQUIREMENTS (cont'd)

ITEM	NO. ITEMS (NO INTER-FACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT* OUTPUT/INPUT (NOMINAL)	REMARKS
SENSORS (cont'd)				
• Rate sensors temp sensor	1 (1)	D/A	As appropriate to rate sensor requirement.	Temp. diode.
• Vertical gyro 1	1 (2)	D/A	User selectable; wire wound pot, 0 to +5 VDC typical.	Humphrey VG34-0301-1 ±90° roll, ±60° pitch will be evaluated for use on ROBOT-X; may be flown on POC test flights.
• Vertical gyro 2	1 (2)	D/A	User selectable; carbon film pot, 0 to +5 VDC typical.	Ferranti FS60A ±90° roll, ±85° pitch will be evaluated for use on ROBOT-X; may be flown on POC test flights.
• Vertical gyro temp sensor	1 (1)	D/A	As appropriate to gyro requirement.	For correction of vertical gyro temp. sensitive characteristics.
• Angle of attack sensor	1 (1)	D/A	User selectable; wire wound pot, 0 to +5 VDC typical.	May be used on advanced ROBOT-X airframes; not planned for use on POC test flights.
• Total temp probe	1 (1)	D/A	User selectable; 0 to +5 VDC typical.	May be used on advanced ROBOT-X airframes; not planned for use on POC test flights.

*NOTE: Data given corresponds to actual sensor/autopilot output nominal limits; actual interface will have somewhat larger range in order to accommodate off-nominal characteristics.

TABLE 10 PEGASUS II SIMFAC INTERFACE REQUIREMENTS

ITEM	NO ITEMS (NO INTERFACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT OUTPUT/INPUT (NOMINAL)	REMARKS
SERVO COMMANDS				
• Pulse Width	8 (8)	A/D	0-5 V, 1-2 ms pulse, repeats 30-60 Hz, LSTTL drive.	Up to 8 independent PW proportional commands output from autopilot and digitized for input into SIMFAC as airframe control commands.
AUTOPILOT DIGITAL INTERFACES				
• Serial 1 (Autopilot input)	1 (1)	D/D	0-5 V, 10K impedance, 0 volt start bit, 8 bits of data, LSB first, 1 stop bit.	Uplink radio command input line.
• Serial 2 (Autopilot output)	1 (1)	D/D	0-5 V, 1K internal resistance, 0 volt start bit, 8 bits of data, LSB first, 1 stop bit.	Downlink telemetry output line.
• bit inputs	8 (8)	D/D	8 bits max, TTL level CMOS impedance, except interrupts (two) (22K impedance), CMOS type diode protection (direct input).	Intended for monitoring events onboard the aircraft, such as equipment status. Interrupts demand immediate response.
• bit outputs	8 (8)	D/D	8 bits max, 1 LSTTL drive.	Intended for controlling equipment onboard the aircraft and indicating autopilot status. Could be used to deploy recovery system.

TABLE 10 PEGASUS II SIMFAC INTERFACE REQUIREMENTS (cont'd)

ITEM	NO ITEMS (NO INTERFACES)	TYPE OF INTERFACE REQUIRED	AUTOPILOT OUTPUT/INPUT (NOMINAL)	REMARKS
SENSORS				
• Analog input	16 (16)	D/A	8 channels with signal conditioning, high impedance (≥ 5 MOhms), 0-5 volt range (unconditioned), ±12 V max range (conditioned inputs), 14 bit resolution.	Generic input channels for sensors (see Table 9 for typical sensor characteristics).
• RPM inputs	2 (2)	D/A	2 channel with 10K impedance, 0-5 V range, under/over voltage protection.	Provided separately from above as different input impedance requirement.

TABLE 11 ZEROTH GENERATION SIMFAC - PROPOSED COMPAQ PLUS CONFIGURATION (cont'd)

ITEM	NO.	DESCRIPTION	($ Cdn. including FST and applicable duty)
14	2	Lab Master analog output cables (Tecmar 23009)	$ 72.
15	1	Lab Master parallel output cable (Tecmar 24009)	$ 36.
16	1	Lab Master timer output cable (Tecmar 28009)	$ 36.
17	1	LABPAC software support package (Tecmar 30009)	$ 778.
18	4	DADIO boards (Tecmar 20008) each with 4 independent D/A converters, 12-bit resolution, 200 KHz conversion rates, jumper-selectable output ranges (0 to +5 V, 0 to +10 V, 5 V, 10 V), 24 parallel I/O lines.	$ 2484.
19	16	DADIO D/A output cables (Tecmar 21008)	$ 576.
20	1	DADIO parallel output cable (Tecmar 22008)	$ 36.
		TOTAL	$16570.

NOTE: Costs are based on budgetary estimates obtained from Compaq Computer Corporation and Tecmar, Inc. dealers.

TABLE 12 ZEROTH GENERATION SIMFAC - PROPOSED HP INTEGRAL PERSONAL COMPUTER CONFIGURATION

ITEM	NO.	DESCRIPTION	($ Cdn. including FST and applicable duty)
1	1	Hewlett-Packard Integral Personal Computer complete with 256 Kbytes ROM, 512 Kbytes RAM, Motorola 68000 16/32-bit microprocessor, 16-bit graphics processing unit, 710 Kbyte double-sided, double density 3½-inch microfloppy disk drive, HP-UX/RO UNIX operating system, HP Windows software, HP-IB (IEEE-488) interface bus, 2 HP human interface loops and 2 expansion ports.	$ 8823.
2	1	256 Kbyte RAM card (HP 82925A).	$ 1234.
3	1	HP-UX Technical Basic	$ 462.
4	1	Carrying case with strap (HP 13269Y).	$ 191.
5	2	RS-232C interfaces (HP 82919A).	$ 690.
6	1	General Purpose Input/Output (GPIO) interface (HP 82923A).	$ 878.
7	1	HP-IB 2 meter right angle cable (HP 82977B).	$ 194.
8	1	Bus expander (HP82904A)	$ 2271.
9	1	15 Mbyte Winchester (HP 9134D)	$ 5142.
10	1	HP multiprogrammer with one set documentation and software (HP 6942A, Opt 010-386).	$ 6605.
11	1	Multiprogrammer extender (HP 6943A)	$ 4954.
12	1	Extender kit (HP 14700A).	$ 758.
13	1	Chaining cable (HP 14702A).	$ 379.
14	15	HP D/A voltage converter cards, 12-bit resolution, -10.240 V to +10.235 V, 5 mA load current (HP 69720A).	$ 15915.

TABLE 12 ZEROTH GENERATION SIMFAC - PROPOSED HP INTEGRAL PERSONAL COMPUTER CONFIGURATION (cont'd)

ITEM	NO.	DESCRIPTION	($ Cdn. including FST and applicable duty)
15	3	HP D/A current converter cards, -20.480 mA to +20.475 mA (HP 69721A).	$ 4092.
16	8	HP A/D converter cards, 12-bit resolution, 10 V, 33,000 sendings/sec (HP 69751A).	$ 11512.
		TOTAL	$ 64100.

NOTE: Costs based on budgetary estimates obtained from Hewlett-Packard dealers.

TABLE 14. ZEROTH GENERATION SIMFAC - COMPARISON OF PROPOSED CONFIGURATIONS

ITEM	CONFIGURATION 1	CONFIGURATION 2	CONFIGURATION 3
Computer	Compaq Plus portable personal computer.	HP Integral personal computer.	Masscomp MCS-531x.
Operating System	DOS 2.2.	HP-UX/RO.	RTU-01 UNIX based RTOS.
CPU	Intel 8088.	Motorola 68000 16/32 bit microprocessor running at 8 MHz clock rate.	Motorola 68010 32-bit microprocessor running at 10 MHz clock rate.
Parallel Processing Capability	No.	No.	Yes - a Motorola 68000 second processor may be added for approximately 20% increase in system price.
Floating Point Processor	No.	No.	Yes - Masscomp FP-501.
Capability for real-time 6 DOF simulation	Very limited.	Limited.	Yes.
Suitability for ROBOT-X ground station	Yes.	Yes.	No - Too expensive and not portable.

TABLE 14. ZEROTH GENERATION SIMFAC - COMPARISON OF PROPOSED CONFIGURATIONS (cont'd)

ITEM	CONFIGURATION 1	CONFIGURATION 2	CONFIGURATION 3
Mass storage	One 360 Kbyte diskette drive one integral 10 Mbyte fixed disk drive.	Double sided, double density 3½" microfloppy built-in disk drive, 710 Kbyte capacity; 15 Mbyte Winchester disk.	1 Mbyte 5¼" floppy disk, 50 Mbyte 5¼" Winchester Disk, ¼" 45 Mbyte 5¼" Cartridge Mag tape.
A/D channels	16 uniplar or 8 bipolar; 12-bit resolution; 30 KHz conversion rate.	8 bipolar; 12-bit resolution.	16 bipolar; 12-bit resolution; 1 MHz conversion rate; programmable gain.
Fortran	Yes - Microsoft Fortran.	No.	Yes. Fortran 77 for direct DRES VAX 6 DOF software compatibility.
D/A channels	18 independent; jumper selectable output ranges; 12-bit resolution; conversion rate 200 KHz.	18 independent; 12-bit resolution.	16 independent; 12-bit resolution.
Service Network	No.	Yes.	Yes.
Availability	Complete system in 2 months from RPO.	Complete system in 3 months from RPO.	Complete system in 3 months from RPO.
Cost (Cdn. $, FST & duty included)	$16.6K as configured in Table 11.	$64.1K as configured in Table 12.	$80.5K as configured in Table 13.

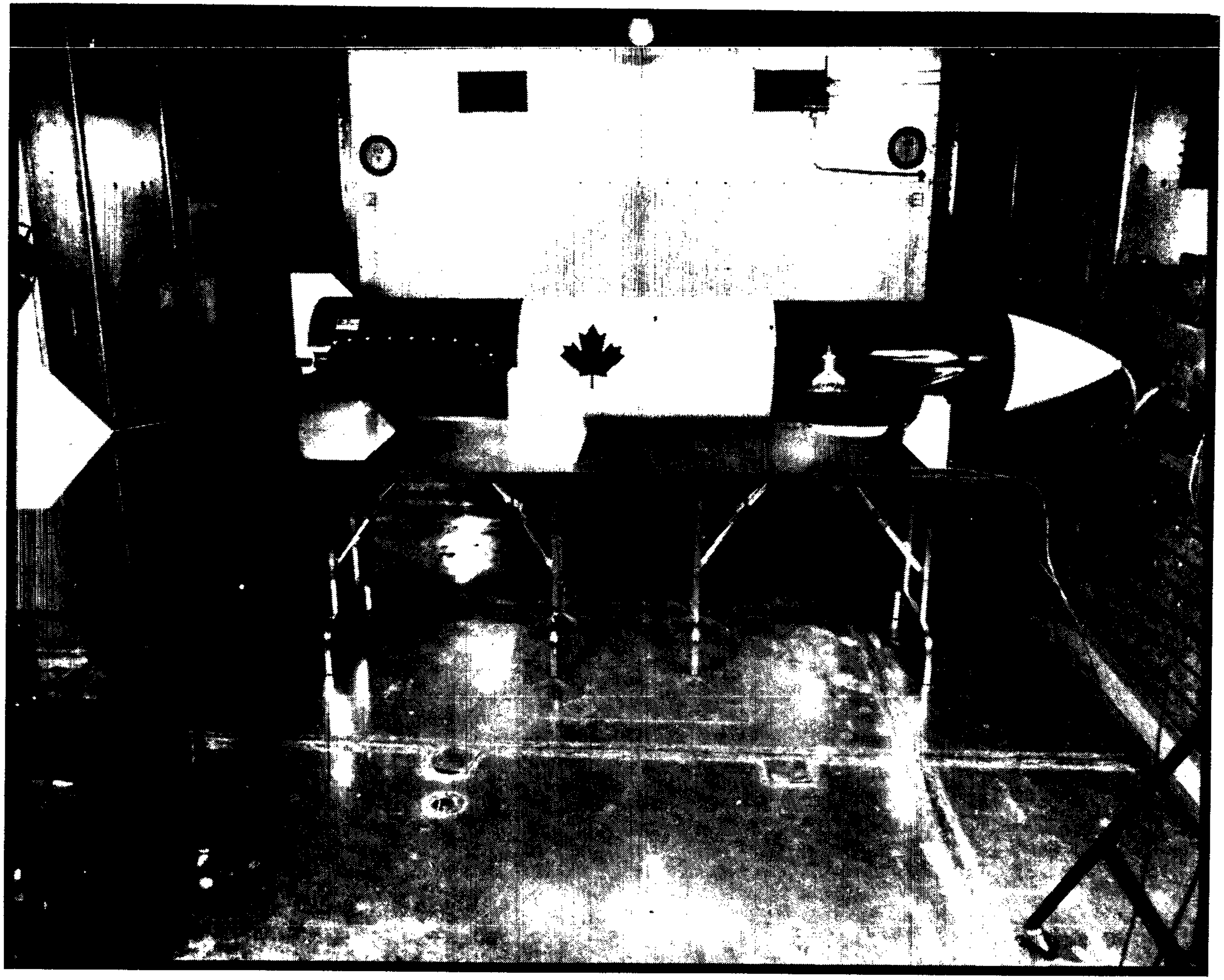

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Figure 1. ROBOT–X

Photo taken in AETE walk–in enviromental test chamber, CFB Cold Lake
(Courtesy Aete Photo Section)

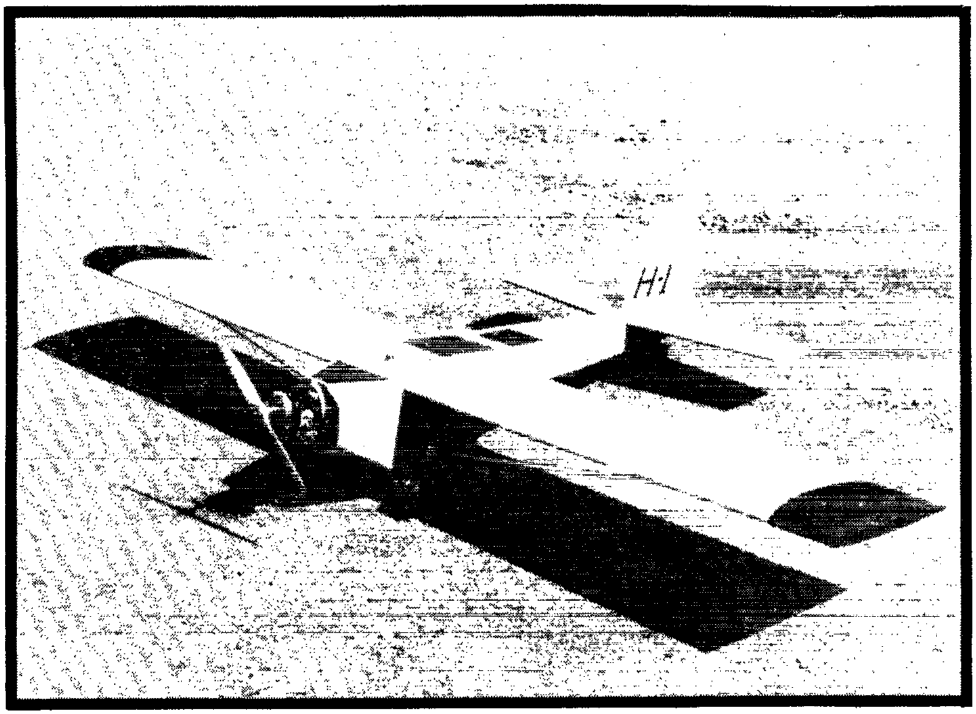

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Figure 2. HULK

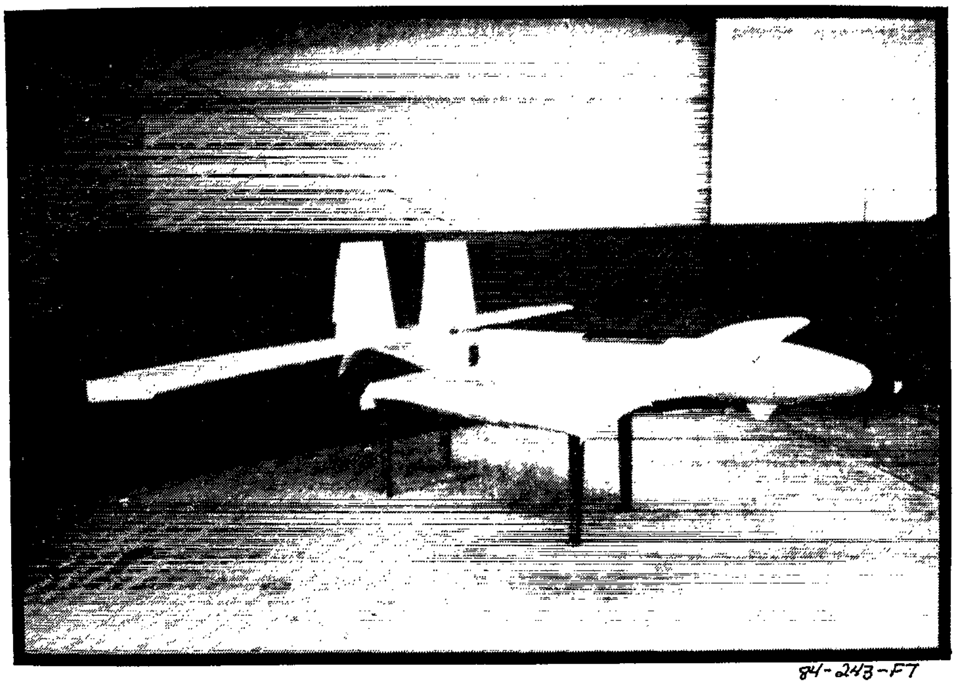

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Figure 3. RESEARCH REMOTELY PILOTED PLATFORM (R^2P^2) S/N 001

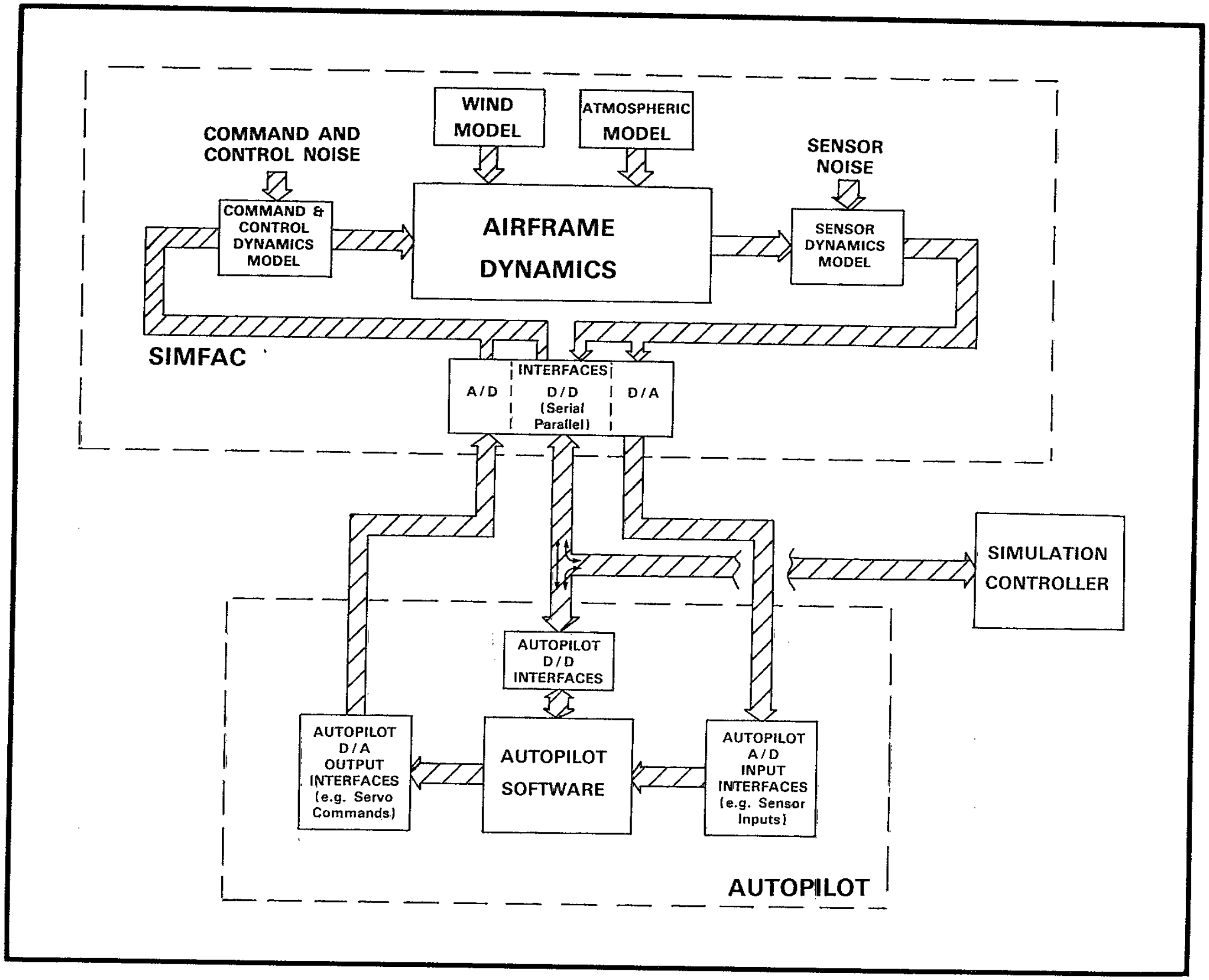


Figure 4. SIMFAC: AUTOPILOT SOFTWARE DEVELOPMENT CONFIGURATION

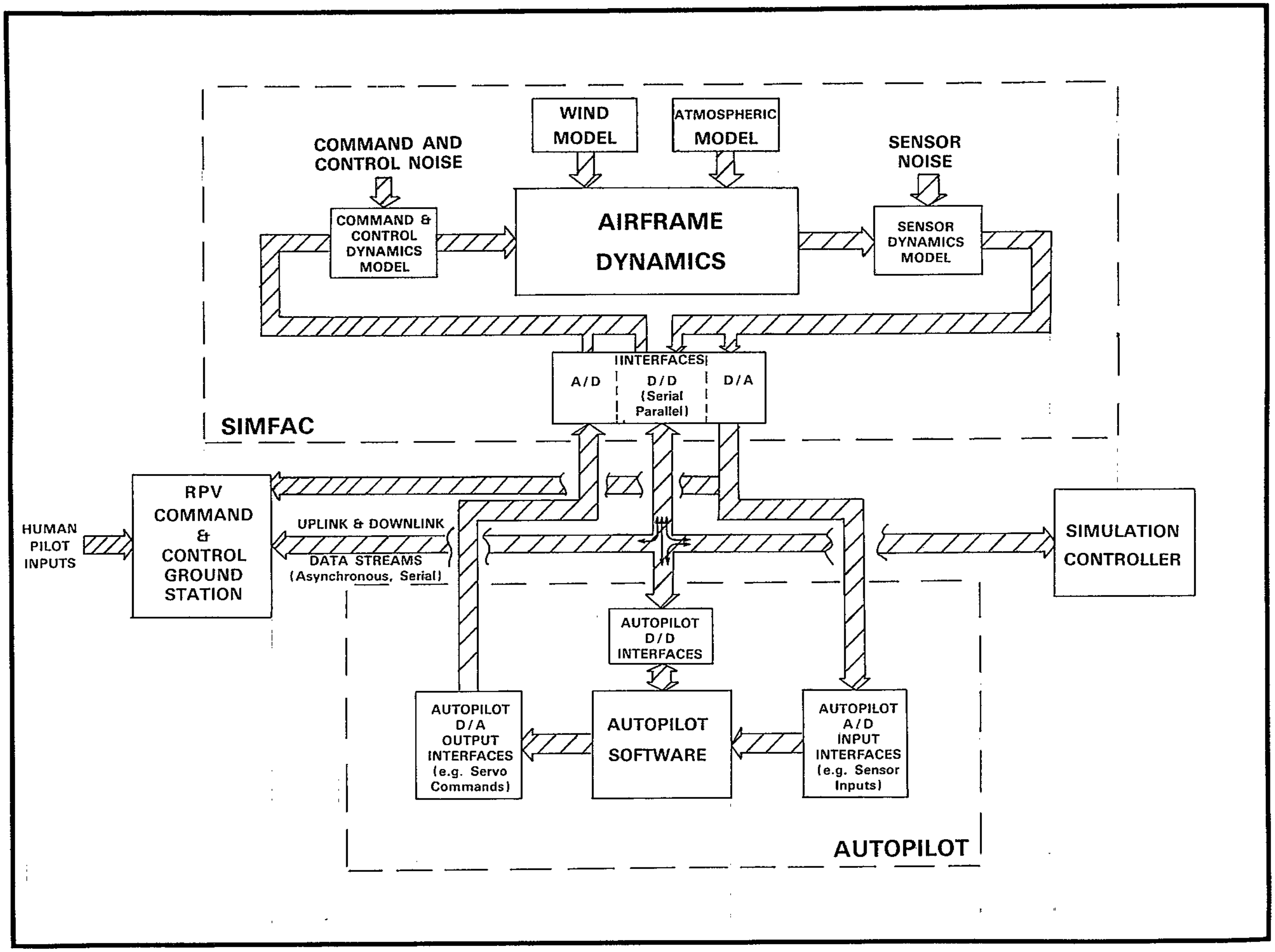
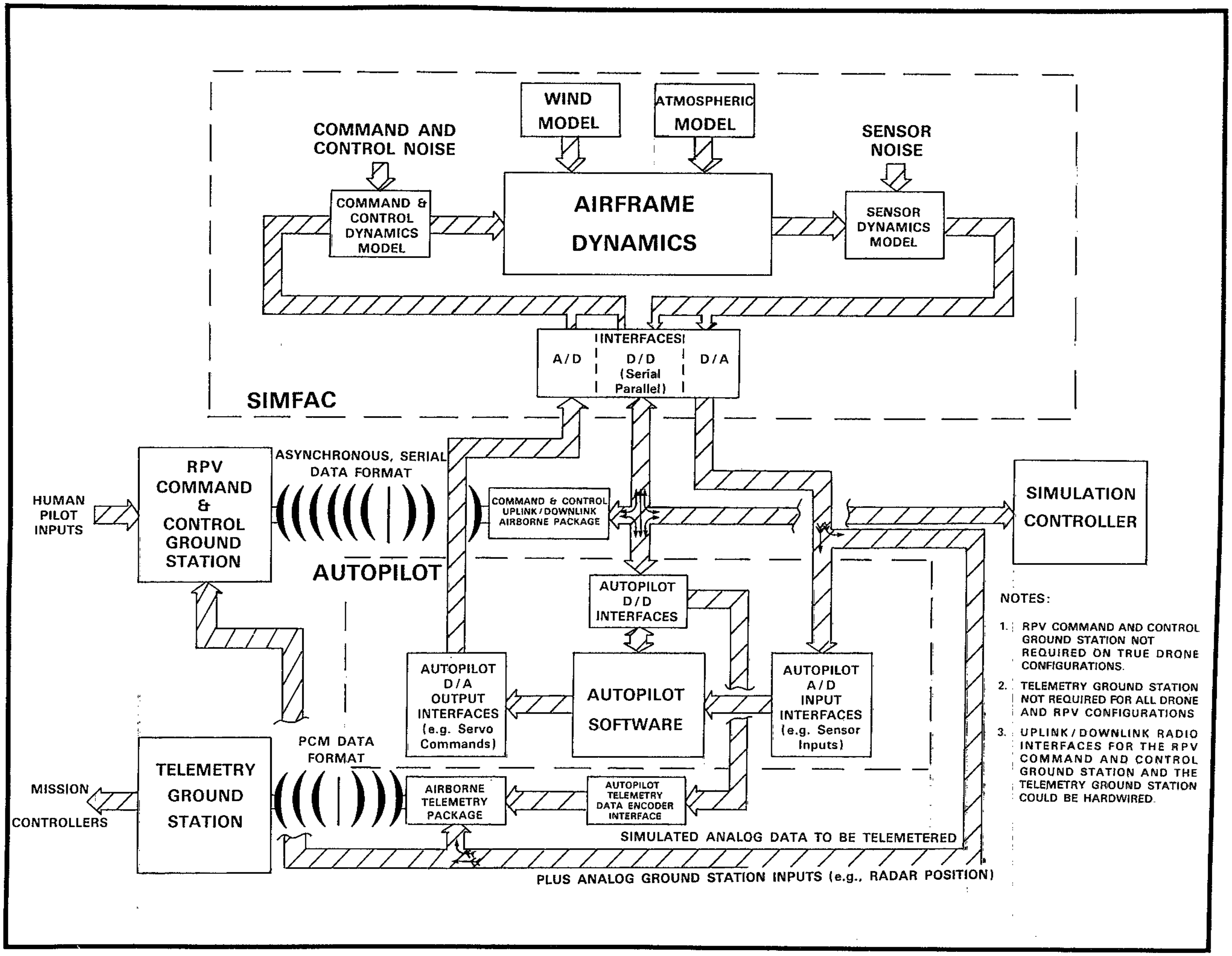


Figure 5. SIMFAC: RPV PILOT TRAINING CONFIGURATION



NOTES:

1. RPV COMMAND AND CONTROL GROUND STATION NOT REQUIRED ON TRUE DRONE CONFIGURATIONS.
2. TELEMETRY GROUND STATION NOT REQUIRED FOR ALL DRONE AND RPV CONFIGURATIONS
3. UPLINK/DOWNLINK RADIO INTERFACES FOR THE RPV COMMAND AND CONTROL GROUND STATION AND THE TELEMETRY GROUND STATION COULD BE HARDWIRED.

Figure 6. SIMFAC: SYSTEM SIMULATION CONFIGURATION

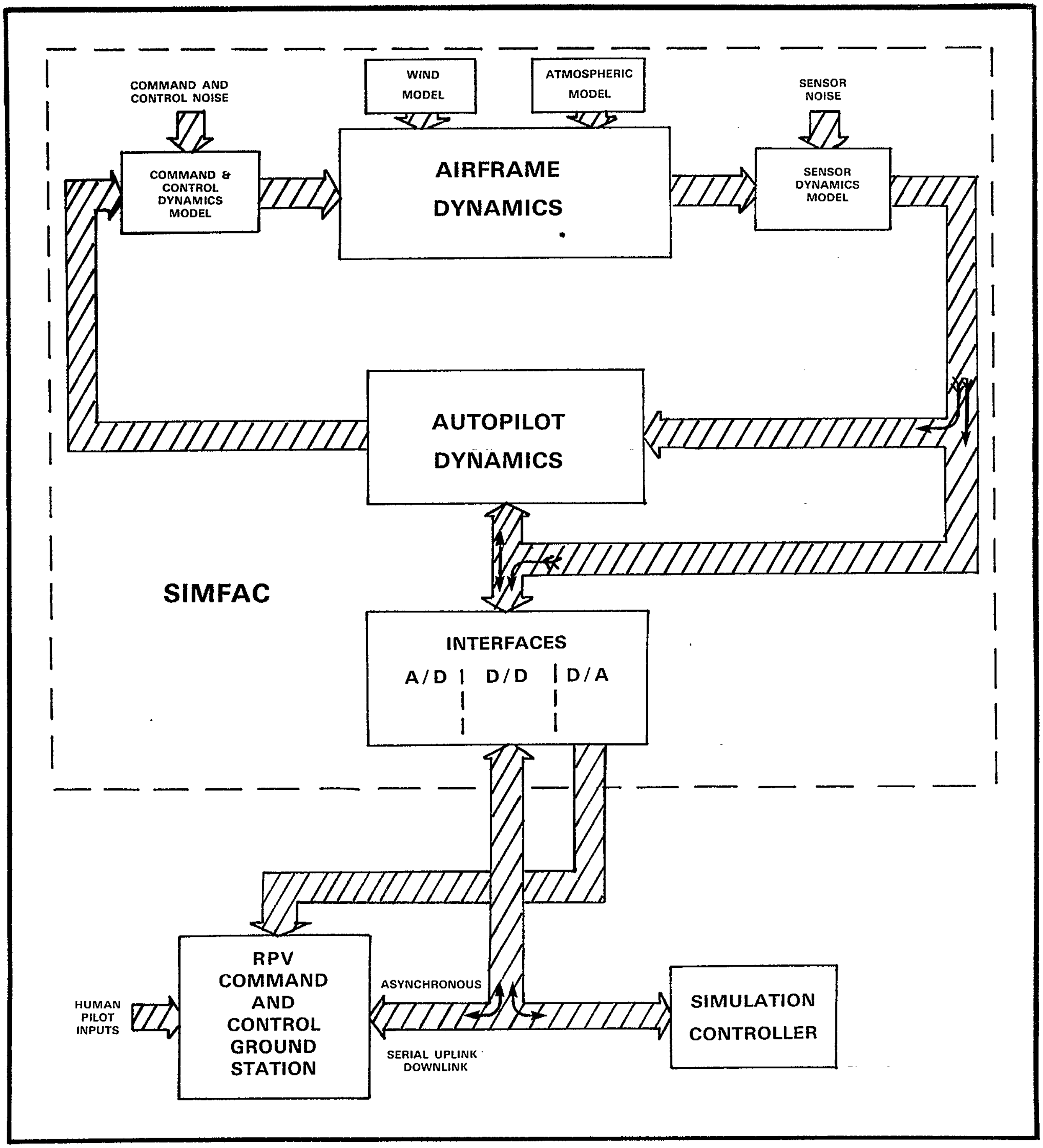


Figure 7. SIMFAC: RPV COMMAND AND CONTROL GROUND STATION DIRECT INTERFACE CONFIGURATION

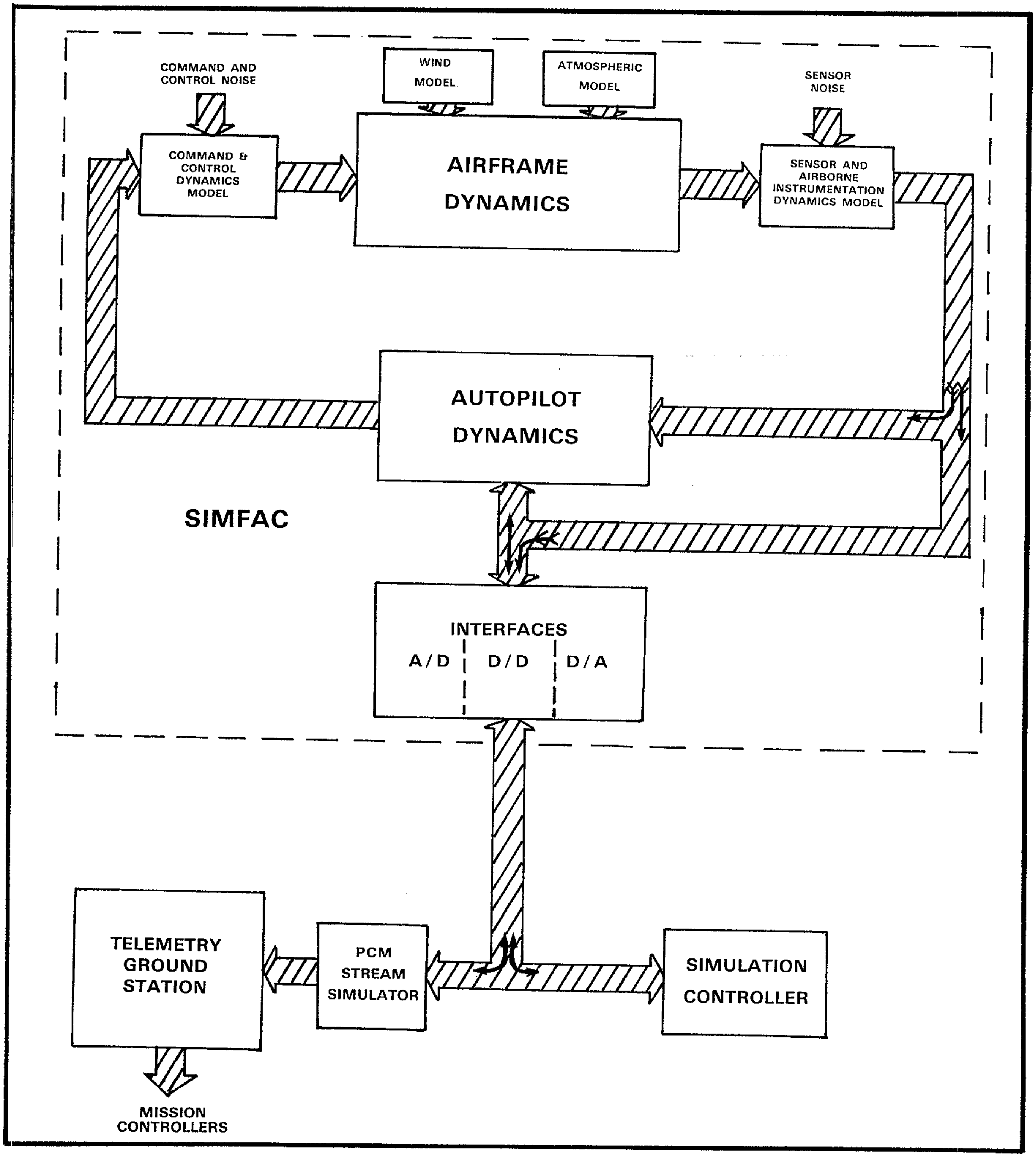


Figure 8. SIMFAC: TELEMETRY GROUND STATION DIRECT INTERFACE CONFIGURATION

UNCLASSIFIED

This Sheet Security Classification

KEY WORDS

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Drones
Flight Dynamics
PEGASUS
R^2P^2
Real-Time simulations
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