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THE MARS AIRPLANE

J. R. French
Jet Propulsion Laboratory
Pasadena, CA

ABSTRACT

The concept of the Mars Airplane was developed as a potential vehicle for unmanned Mars exploration. This paper suggests that its most appropriate use would be as an unmanned adjunct to a manned mission. Functions such as reconnaissance, exploration, remote delivery of instruments, etc. are possible. Several operational aspects of such a vehicle are unique compared to Earth operating aircraft.

BACKGROUND

The Mars Airplane concept was developed by JPL and Dryden Flight Research Center personnel in 1977/78 as a potential system for unmanned exploration of Mars. The concept grew out of studies at Dryden of an unmanned aircraft capable of operating for long periods at altitudes near 30.5 km (100,000 ft). Such altitudes at low airspeeds dictated a non-airbreathing engine. This together with the fact that atmospheric density at 30.5 km on Earth is much like that near the Martian surface suggested the possibility of a Mars airplane. Initial concepts by JPL and Dryden looked promising and small contracts were let in 1977 and 1978 to Developmental Sciences Inc. (DSI) to study Mars Airplane design (Ref. 1). In addition, an ad-hoc science working group was convened to study what the Mars Airplane might do (Ref.2).

This paper summarizes the results of those studies and adds some additional thoughts of the author. Two versions of the airplane were studied: 1) the cruiser, which could not land, but flew, taking data until its fuel was exhausted and, 2) the lander which was capable of repeated controlled landings and takeoffs. Only the latter version is considered here since, for a manned mission, reusability of even robot equipment is desirable.

ENGINEERING ASPECTS

Because of the limited data rate capability and desire to minimize power requirements, the Mars Airplane was designed for a cruise speed of 90 m/sec (175 kt). The low atmospheric density (<1% Earth) dictated an airfoil with high cruise lift efficiency and a high aspect ratio wing.

This combination together with the low gravity yields excellent range capability as will be discussed later.

To minimize both mass and drag as well as for convenience in stowage, an inverted Vee tail was used. The overall configuration appears in Figure 1 (from Ref. 1). The resemblance to a modern high performance sailplane is obvious. The dimensions are similar as well. The propeller is quite large by Earth standards in order to perform efficiently in the thin atmosphere. The tail is also large to allow for large center-of-mass travel.

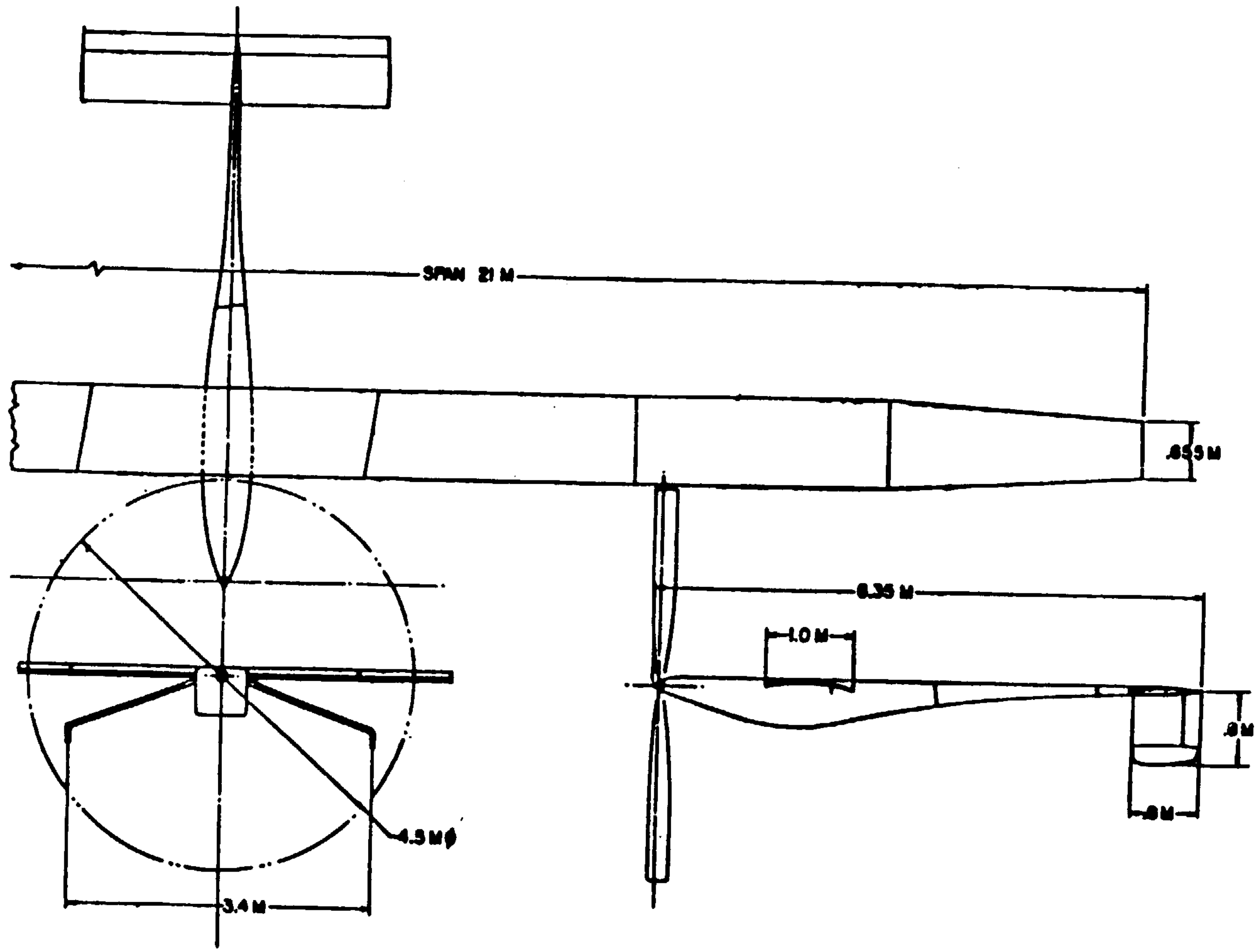
Martian conditions at these airspeeds result in a very low Reynolds number for a vehicle of this size. Specifically, the Reynolds number for the Mars Airplane at cruise is of the order of 4.5×10^4 compared to 3×10^6 for a typical light aircraft. Most experience in this range is with free-flight model aircraft. Thin high efficiency airfoils derived from the work of Eppler at the University of Stuttgart were used in the DSI design Ref.1. Since the time of that design (1978) there has been increased interest in low Reynolds number airfoils and some of this new work may be applicable.

The baseline powerplant for the Mars Airplane was a hydrazine-fueled reciprocating piston engine developed by Jim Akkerman of NASA Johnson Space Center. This engine functions much like a reciprocating steam engine. The hydrazine decomposes into a hot gas in a catalyst bed similar to that used in monopropellant rocket engines. This gas is then valved into the cylinder of the reciprocating engine which vents it overboard following the power stroke. This engine was flown successfully on the Dryden "Mini-Sniffer" aircraft. The horsepower requirement for the Mars Airplane as designed is 15HP. The complete engine when developed for Mars should have a mass of about 13kg. The cruise specific fuel consumption is expected to be 2.2 kg/HP-hr (4.85 lb/HP-hr).

An alternative powerplant was also investigated. This consisted of a light-weight samarium-cobalt electric motor with a gearbox and a solid state inverter. The unit was expected to weigh roughly the same as the hydrazine engine, assuming very high performance of the Sa-Co motor. At the time of the design, this was considered speculative by some and needs to be reinvestigated. Electrical power was provided by primary batteries, probably lithium thionyl chloride. The energy density usually

FIG. 1

BASIC AIRPLANE CONFIGURATION



quoted for these batteries is about 66 watt-hr/kg (300 watt-hr/lb). For this study a value of 649 watt/hr-kg (295 watt-hr/lb) was used. A much higher energy density of 1199 watt-hr/kg (545 watt-hr/lb) was also evaluated. This required heroic weight reduction measures in the battery package and must be considered speculative.

Landing and takeoff were to be done vertically using variable thrust monopropellant rocket engines derived from the Viking lander. The fuel for these engines is hydrazine. In the case of the hydrazine engine airplane, the rocket engines and the reciprocating engine would draw propellant from a common supply, whereas the electric vehicle required a hydrazine supply just for the rockets. (Note that a disadvantage of the electric airplane in regard to landing and takeoff is that it never becomes lighter than it was initially, while the chemically powered version loses mass as propellant is burned, thus making landing and takeoff toward the end of a particular trip much less costly in fuel.) For a manned mission, the airplane would presumably be reused in a manner similar to remotely piloted vehicles (RPVs) on Earth. In this case, the chemically fueled version may be more desirable, since rechargeable batteries have much lower energy density than the primary batteries originally postulated. If the capabilities of the manned surface base included In-Situ Propellant Production (ISPP), the airplane could be supplied with these propellants. Otherwise, residual propellant from the lander stage should supply ample quantities. Engine types which might be considered include reciprocating, gas turbine, and electric motors driven by fuel cells. (As an aside, if propellant manufacturing capability exists to generate CO and O_2 from the Martian atmosphere, a fuel cell operating on these materials would be most useful for airplanes, rovers and other portable power needs rather than using the combination in a combustion mode. This concept deserves further attention.)

PERFORMANCE

The hydrazine powered version of the Mars airplane was estimated to have an operating ceiling of 15 km on a Mars standard day at minimum mass (150 kg.) At maximum gross mass of 300 kg, the ceiling would be about 8 km, from which altitude the power-off glide range would be over 250 km. Initial rate of climb at low altitudes is estimated to be 12.7 m/sec .PA

(2500 ft./min.), which is quite respectable and bodes well for terrain avoidance capability and ability to cope with downdrafts.

Figure 2 (Ref. 1) presents range performance. The numbers are quite respectable even if one ignores the rather debatable upper curve. These numbers make no allowance for landing propellant, and would be typical of a reconnaissance sortie with landing on a prepared surface at the base rather than vertically. Maximum sortie radius would be half the range. An early landing at high mass could reduce the range by 30-40%, while retaining fuel for a final vertical landing at low mass would have a lesser penalty.

OPERATIONS

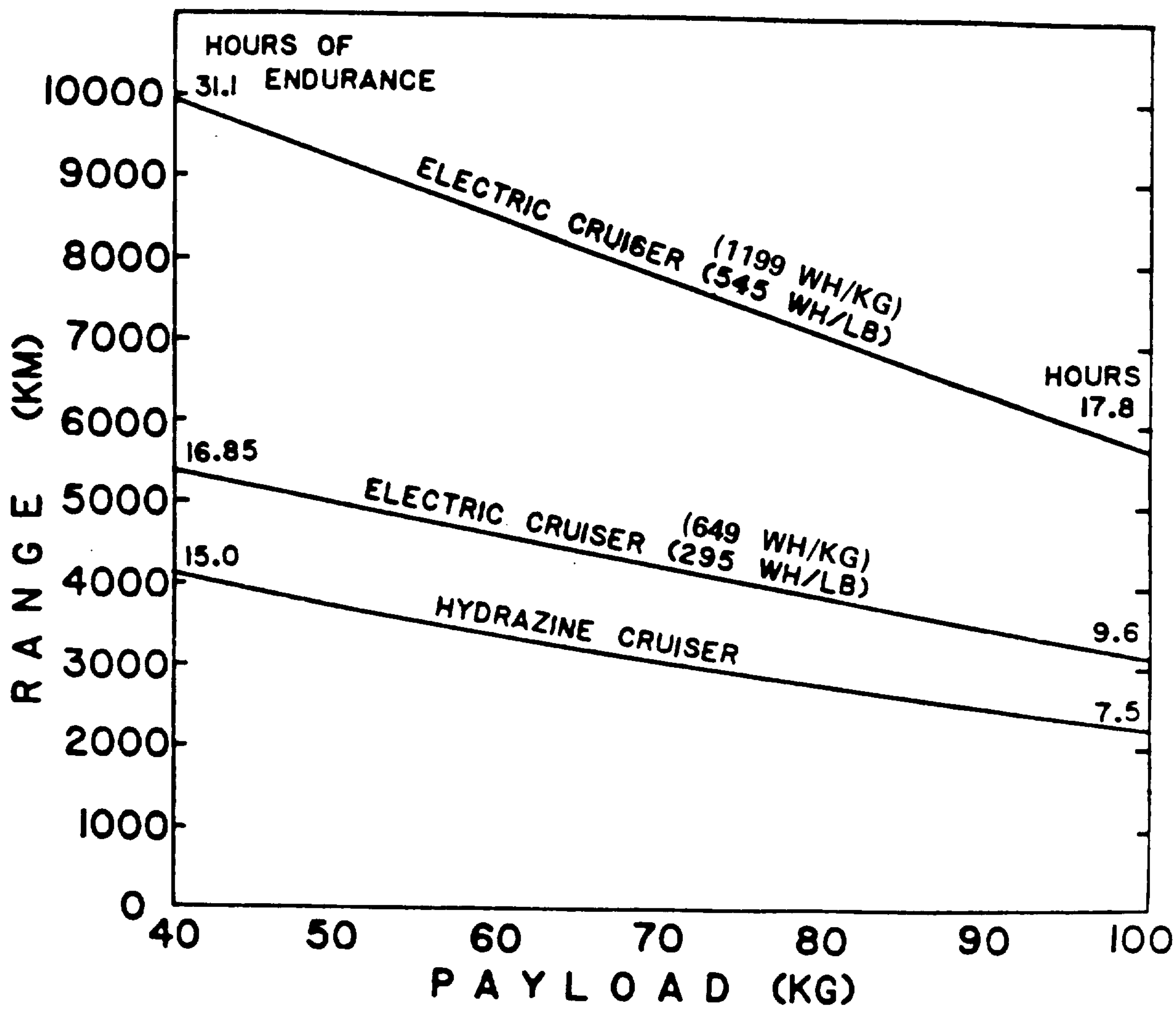
The vehicle would be unstowed after landing and assembled by the crew much in the manner of sailplanes on Earth. (This avoids one of the serious drawbacks of the unmanned version; namely, how to achieve self-deployment of a very complex folded structure while dangling from a parachute.) Launch might be via catapult or the internal rockets. Guidance and navigation would be preprogrammed, probably using inertial systems with landmark identification for updates. Upon its return to the vicinity of the base, control would be assumed by a crew member on the ground who would control the landing, following normal Earth RPV practice.

Figure 3 shows a possible vertical takeoff profile suggested by DSI. It is the author's opinion that propellant could be saved by starting the propeller as soon as ground clearance is adequate and accelerating directly into wing-supported flight rather than following the lofted trajectory shown. Landing would invoke a technique called "stable stall".

Stable stall is a technique originally developed for the recovery of free-flight model aircraft. Briefly, it involves deflecting the horizontal stabilizer to a very high angle, placing the aircraft in a deep stall. The aircraft descends vertically in a flat attitude at a modest and quite predictable rate. NASA studies show that the technique can be satisfactorily applied to larger aircraft as well. In the case of the Mars Airplane, the descent terminates in a rocket-braked landing. Figure 4 shows the profile of such a descent. Creation of a runway at the base site would allow for conventional landing thus eliminating the need to

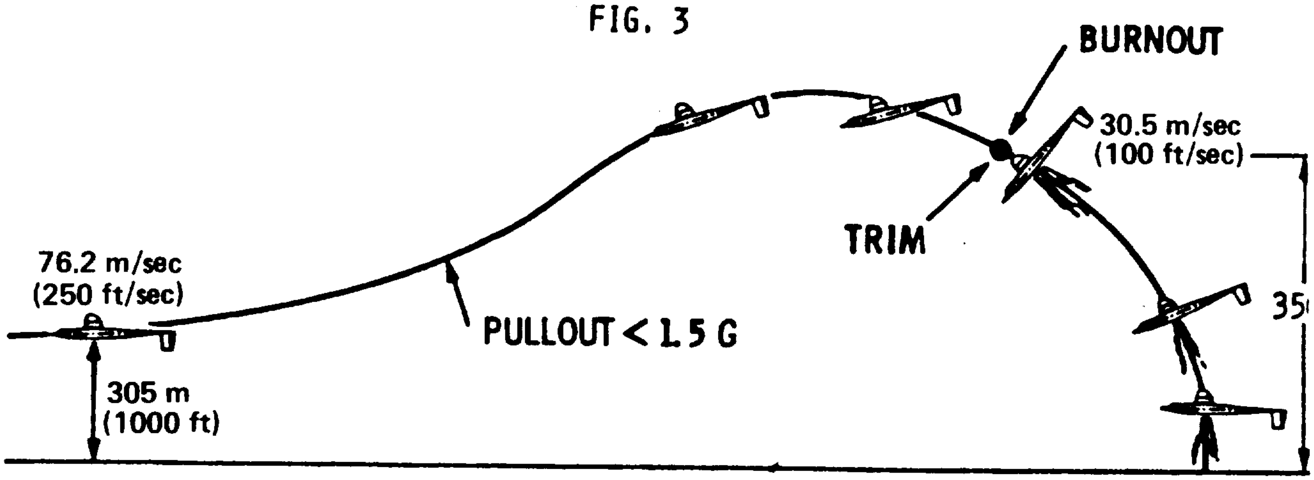
FIG. 2

CRUISE PERFORMANCE



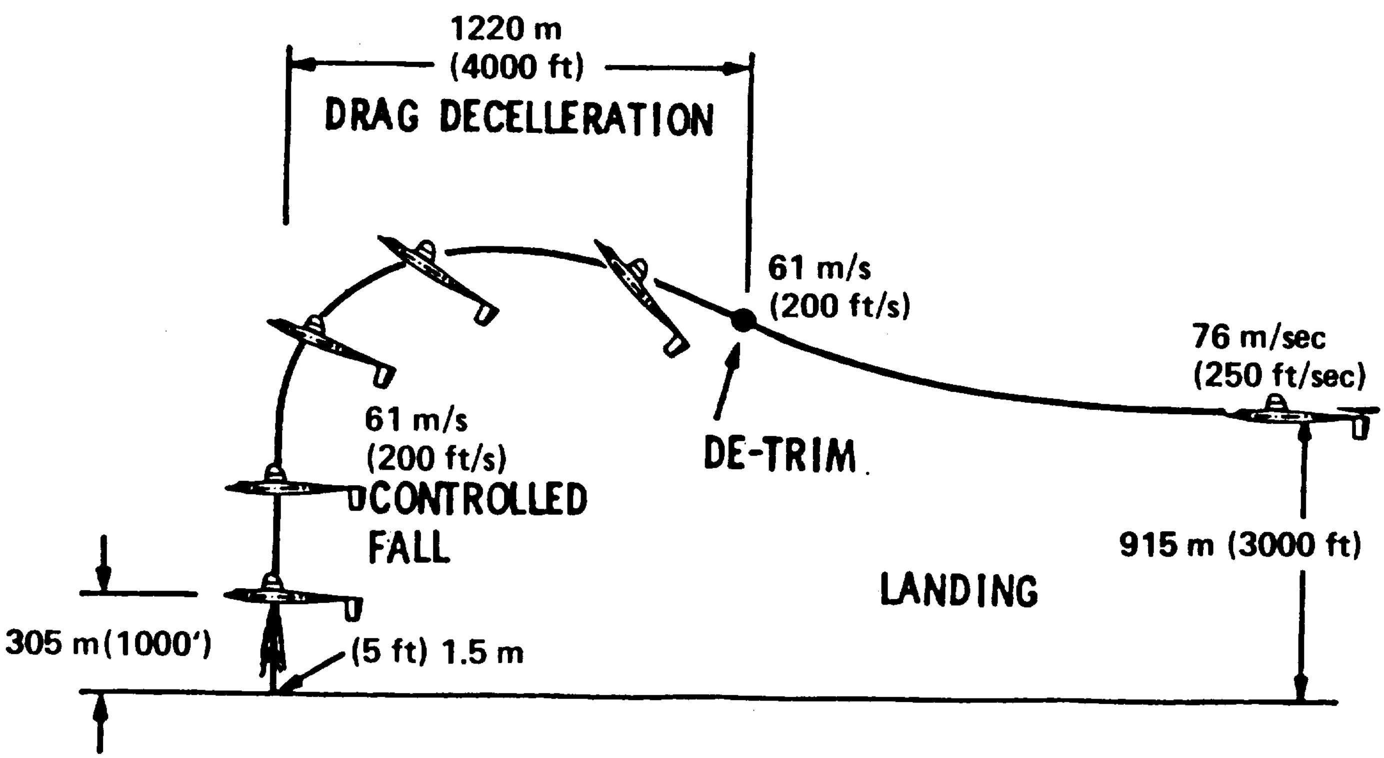
AUW	300 KG	PROP EFFICIENCY	.85
WING SPAN	21 M	HYDRAZINE ENGINE	
WING AREA	20 M^2	CRUISE SFC	4.85
CRUISE ALTITUDE	1 KM	ELEC. MOTOR EFFICIENCY	.85
LIFT/DRAG AT 300 KG	27.75	AUX. POWER CONSUMPTION	.4 KW

FIG. 3



VERTICAL TAKEOFF

FIG. 4



VERTICAL LANDING

carry propellant for a final vertical landing, on each sortie. To minimize length of landing gear, all landings would be made with the propeller stopped in the horizontal position. Mass could be saved by using skids rather than wheels if only vertical or catapult takeoff is used.

FUNCTIONS OF A MARS AIRPLANE

An unmanned Mars Airplane could perform a variety of useful functions in support of a manned Mars mission. Examples include:

1) Reconnaissance sorties to provide detailed route maps in support of surface traverses by the crew in rover vehicles.
2) Scientific surveys of large regions or particular sites distant from the base or otherwise difficult to reach.
3) Deployment of an array of remote observing stations (penetrators, surface packages, or both) either by air drop or by landing.
4) Delivery of high priority hardware to a crew far from base on a surface sortie and/or return of priority samples, etc. from the rover crew to the base.

Other functions will probably arise as the capability of the Mars airplane becomes better understood and the mission definition improves. Even the set of functions listed above could be of substantial benefit. For example, detailed aerial maps will allow more rapid cross-country traverses and warning of possible hazards. Optimum routes can be selected ahead of time. Large area aerial surveys supplementing work done from orbit can be of great geological significance. The ability to deliver science instrument packages to remote locations will be of substantial benefit, since it could not be done by surface rover but would have to be done from space using individual entry packages. The ability to deliver supplies of one sort or another to a rover crew could be vital in case of hardware failure or a medical emergency.

MANNED MARS AIRPLANE

The question will inevitably arise as to feasibility of a manned airplane for Mars. While (to the author's knowledge) this has not been studied, there seem to be no technical reasons to prevent it. In fact, the Mars Airplane described herein has adequate payload mass capacity to carry any normal human. However, it could not carry a human in a spacesuit and full complement of life support equipment without exceeding the design mass. Also, the compact fuselage volume lacks room for such a payload. A realistic manned Mars airplane would have to be considerably larger than the vehicle described here, especially since it would probably be desirable to carry a crew of two and a payload. The mental picture that develops is that of a vehicle of the general size and appearance of the U-2, except being propeller driven.

The technical difficulties involved in creating such a vehicle do not appear any more formidable than those involved in the small unmanned craft. Some practical difficulties are stowage (especially for atmospheric entry), assembly and handling on Mars, and propellant consumption.

CONCLUSION

Based upon the work summarized in this paper, there appear to be no serious technical difficulties involved in designing and operating a Mars Airplane. It further appears that such a vehicle could be most useful in extending the capability of the Mars surface crew and possibly enhancing safety.

REFERENCES

1. Development Sciences Inc., Final Technical Report on JPL Contract No. 955012 "A Concept Study of a Remotely Piloted Vehicle for Mars Exploration", August 1, 1978.
2. JPL Publication 78-89 "Final Report of the Ad Hoc Mars Airplane Science Working Group", November 1, 1978.