WISSENSCHAFTSRAT

Drs. 5370/02
Berlin, 12 July 2002

High Altitude and Long Range Research Aircraft (HALO)

Note:

This statement given by a subgroup of the steering committee „Large research facilities for basic research“ of the German Science Council concentrates on the scientific and technical investigation of the project. The statement if the project should be funded or not is given by the Science Council itself by a final evaluation of all nine projects. This statement is given in a separate report.

A. Introduction and Background

A.I. Field of Research

The most fundamental development in atmospheric research has been the integration of the atmospheric sciences with biology, hydrology, and some aspects of the socio-economic sciences into the beginnings of an Earth System Science. This shift in worldview from a discipline-oriented or sectoral perspective to an integrated approach has changed the way of conducting research. Investigations tend to involve scientists from several disciplines, require measurements of large numbers of parameters even within a particular discipline, and cover greater spatial and temporal scales.

Research aircraft have been and will remain essential platforms to make the measurements required to improve knowledge in the following active fields of research: atmospheric chemistry and climate research, meteorology, biogeochemistry, polar research, oceanography, geography, ecology, glaciology, and environmental research in general. Research aircraft are also needed for development and testing of remote sensing, telecommunications, and aerospace scientific and long-term operational applications in general. The great scientific, technological and societal relevance of these research fields justifies the proposed large facility High Altitude and Long Range Research Aircraft (HALO). Important requirements include a long range (>8000 km), a high certified ceiling altitude (15-16 km) and a high payload capacity (about 3000 kg). It is important to note that HALO must be flexible enough in its performance so that it can also be used extensively for all other Earth research disciplines and will be available for remote sensing and telecommunications applications.

Some recent scientific developments of particular relevance to HALO are summarised below:

1. Atmospheric chemistry and climate research

Important progress has been made in the understanding of the processes determining the amount and distribution of the stratospheric ozone layer, the role of man-made emissions in the oxidation power of the troposphere, transfer of solar and terrestrial radiation within the earth's atmosphere, and the radiative forcing of climate by increasing greenhouse gases and aerosols.

2. Biogeochemistry and biosphere/atmosphere interactions

The Earth's atmosphere is to a great extent a product of biospheric processes. With very few exceptions, all major and minor gases in the atmosphere have important, often dominant, biospheric sources and sinks. This is particularly relevant for the radiatively and chemically active compounds that are at the heart of Global Change, such as CO_2, CH_4, CO, O_3, NO_x, non-methane hydrocarbons, and many aerosol components. The convergence of biospheric and atmospheric research during the last decade of the IGBP has laid the foundations for a developing Earth System Science.

3. Meteorology and weather forecasting

Research in the field of meteorology includes studies for improving understanding of processes impacting weather evolution and its use for improving weather forecast methods. Since the 1980s important progress has been made in the understanding of short range (minutes to days) and medium range weather forecasting (up to about 10 days).

4. Instrument development

Major advances have been made over the past ten years in terms of related instrumentation. According to DLR and MPG the number of presently available instruments would allow to obtain a far more complete picture of the atmosphere than is done in current campaigns. The research aircraft presently available are too small to carry all the necessary instruments. HALO is expected to play a key role in making more complete measurement programs possible, which will stimulate collaborations among universities and research institutes.

German institutes participate strongly and, as part of the European research, at the international forefront of research in atmospheric and Earth sciences. German scientists have played a leadership role in the development and implementation of the International Geosphere-Biosphere Programme (IGBP) and many of its core programmes. The community has gained competence from many previous experiments and from long-term instrument developments. Various EU programmes have led to a strong network of cooperation of atmospheric research institutes all over Europe. The field of research has strongly gained in the past decade from research projects such as the German ozone, climate, and atmosphere research programmes. Moreover, it has benefited strongly from remote sensing projects such as GOME on ERS-2, and the preparation of the sensors MIPAS, SCIAMACHY, ROSIS and others for the ENVISAT satellite. Research projects have been supported among others by BMBF, DFG, ESA, and in particular through a series of EU research framework programmes. Strong research institutes have been developed, some of them newly founded, on the topic of atmospheric research since about 1980 in the old states in West-Germany and since 1990 also in the new states in East-Germany. Recently, a new institute on coastal research has been founded at GKSS.

In the future, the research in this field will develop further with support from the participating research institutions such as MPG, WGL, HGF, universities, etc. Additional support is expected to come from the DFG (the project team plans to apply for special research support), and the EU. The EU presently plans the 6th RTD Framework Programme. Within this programme a thematic area *Global Change* is foreseen with research priority lines “Impact and mechanisms of greenhouse gas emissions and other atmospheric constituents on climate and carbon sinks (oceans, forests and soil)”, “Water cycle”, and “Global climate change observing systems”. The next phase of Global Change research (including IGBP, WCRP, and IHDP) will emphasise integrated studies, which will consider the interactions of human activities, climate change, hydrology, atmospheric processes, and biology. German scientists are actively involved in leading the development of the scientific programme for this new phase of Global Change studies.

Compared to the equipment available in other countries, in particular the USA, German and European research suffers from the lack of a large multi-purpose research aircraft reaching high altitude and long distances. The existing platforms are inadequate to study the necessary range of atmospheric processes, and too small to carry the available instruments, e.g., with respect to multiphase aerosol and cloud physics. This situation will be aggravated in the future because of the need to include a growing range of physical and chemical instrumentation for increasingly complex scientific questions.

The community has used alternative instrument carriers such as commercial aircraft and balloons, and has made observations by remote sensing from the surface including mountain stations and from satellites. All these alternatives have their merits but do not have the far reaching potential of a dedicated and powerful research aircraft. According to the proposers a “flagship” aircraft such as HALO is needed to complement the intellectual leadership of German atmospheric scientists in the implementation phase of the next phase of Global Change research.

Except for some research within the aircraft operating institutions and some minor EU funding for access to European research aircraft supporting training and mobility (STAAARTE and CAATER programmes), the existing research aircraft can be used only with project-specific funding, which makes any long term planning and development difficult or impossible. The DLR internal R&D program provides about 2 M€ per year for support of Falcon usage, which allows for maintaining the operations team and the equipment and for some operation for internal users on smaller campaigns. It is, however, not sufficient to support external users and the desired growing involvement in major international projects. In contrast to the strong institutional support available in Germany for the use of research ships (such as the polar research ship POLARSTERN) and satellites (funded by the European member states via ESA), German aircraft users have to provide the project support required for the use of research aircraft.

It appears unlikely that German users may obtain access to the American research aircraft HIAPER for purely European projects. It is conceivable that European users may fly with some instruments in cooperative projects within a larger US team on board the HIAPER. However, the transfer costs of an aircraft like HALO across the

Atlantic are of the order 100 k€, which will be restrictive for combined usage of the same aircraft in the US and Europe. NCAR has also stated that their planning schedule for the first 5 years of HIAPER, when becoming available, will have no free capacities for such international usage.

In Europe there are no planned activities for an aircraft similar to HALO outside of Germany foreseeable within the mid term future. Within the European Research Aircraft and Sensors for Environmental Research (EURASER) project, which was a concerted action within the 4th EC framework program (FP) and which is being continued in a similar project European Fleet for Aircraft Research (EUFAR) in the 5th FP, the situation regarding the investments for research aircraft in other European countries has been discussed. At the moment, there are 4 European aircraft that have to be replaced within the next few years: The British Hercules C 130 has been replaced by a BAe 146 in 2002. This aircraft (with a ceiling below 10 km) does not compete with the HALO project because it is dedicated mainly to lower- to mid-tropospheric research, including low level flights, with moderate range. With four engines it is particularly suited for low level flights. It appears that the capabilities of the BAe 146 will be very complementary to those of HALO.

The two French aircraft Merlin and Fokker ARAT have only a few months of operation left. It is planned to replace them by a mid size turboprop like ATR or Fokker, which are not comparable to the long range, high ceiling and large payload features of the HALO aircraft. There are plans in France to modify an old Falcon 20, similar to the DLR Falcon. This would not satisfy the requirements for a HALO aircraft. Moreover, the French aircraft suffers from the same aging problems as the DLR Falcon. Even if operation of the aircraft may be feasible for a further 10 to 15 years, the availability of spare parts might become critical with problems for continuous operation.

Without the realisation of HALO, and at the end of the lifetime of DLR's Falcon, Germany would loose its main tool for atmospheric research. The age of DLR's Falcon (26 years) and the long time scales for acquisition, modification and tests for the HALO aircraft (4-5 years) have to be taken into consideration and to be seen in this context. According to DLR and MPG, HALO and Falcon should be operated together for an overlap period, until HALO is fully tested and operational. Through EUFAR a transnational access to HALO will be realised which will provide an effective work share between the European facilities.

A.II. The Facility itself

II.1. Scientific Objectives and Research Prospects

II.1.a) Research Programme

According to MPG and DLR, the HALO aircraft would represent a major improvement in the airborne research capability for research institutes and universities to study atmospheric phenomena and their interactions from local to global scales. Aircraft measurements are particularly valuable to describe processes at the scales of transport and photochemistry. The observed spatial variability in clouds, aerosols, water vapour and ozone, for example, ranges from less than 100 m (turbulence) to more than 1000 km (synoptic weather systems). Since oxidation processes in the atmosphere proceed through radical reaction chains, chemical measurements must typically be performed at a time resolution of seconds to minutes. Because of its relatively large size, HALO would facilitate the deployment of comprehensive sets of instrumentation, as developed within Germany or elsewhere, to simultaneously measure physical and chemical parameters to characterise transport, radiation and chemical processes. Furthermore, the long range and high altitude performance would greatly increase the fraction of the global atmosphere in which fundamental physical and chemical processes could be directly observed.

Improved process understanding from aircraft measurements contributes to the development of meteorological and climate-chemical models. These models serve to study complex interactions and feedbacks, and to perform sensitivity studies and scenario-based predictions. Confidence in models can only be established by showing that processes are well reproduced at all relevant scales. Satellite images, on the other hand, provide generally only a two-dimensional picture of the atmosphere, and at fairly coarse resolution. Aircraft measurements provide the required three-dimensional resolution, and they can be linked with satellite images to construct a more complete view at regional to global scales. Intensive field measurement campaigns with the HALO aircraft would be guided by model forecasts and (nearly) real-time satellite images to plan flight tracks and to independently test models and remote sensing retrieval algorithms.

With the planned measurement campaigns with HALO scientific achievements are expected in nine major research fields:

1. Atmospheric chemistry and global pollution
2. Atmospheric dynamics and transport
3. Cloud research
4. Meteorological research
5. Climate research
6. Global carbon cycle
7. Polar Research
8. Earth Observation
9. Earth Gravimetry and GPS navigation

1. Atmospheric Chemistry and Global Pollution

Providing fundamental data on the oxidising power of the atmosphere

Oxidation processes that "clean" the atmosphere are controlled by hydroxyl (OH) radicals. Oxidation by OH limits the lifetime of most gases so that they do not build up, a vital atmospheric property to safeguard life on our planet. The major source of hydroxyl radicals is in the tropical troposphere up to about 16 km altitude. Controlling processes include short-wave solar radiation transfer (UV penetration through the stratosphere), ozone formation, water vapour abundance and a host of reactions with reduced and partly oxidised gases. Nitrogen oxides (NO_X) play an important role in the recycling of OH radicals. Hydroxyl recycling is key in preventing the chemical system from becoming unstable. This recycling stabilises the system, for example, by buffering it against OH depletion by the anthropogenic increases of methane and carbon monoxide. At present, there are almost no measurements of OH and controlling variables in the tropical troposphere, so that our understanding of this vital system is based exclusively on models untested by observations. Advances in this area of research require simultaneous in situ measurements of many atmospheric variables. Auxiliary information can be obtained from ground-based measurement stations and satellites. HALO is crucial to accommodate the comprehensive instrumentation needed, and to reach polluted (continental) as well as clean (maritime) environments throughout the tropical troposphere.

Exploring UTLS chemistry and dynamics

The availability of HALO would enable studies of the chemistry and dynamics of the upper troposphere and lower stratosphere (UTLS) between about 8 and 15 km altitude. Recent work has indicated that the UTLS contains much more reactive gases than anticipated (e.g., carbonyls and peroxides). This cannot be reconciled with the earlier conception that this part of the atmosphere is relatively inert. In addition, the residence time of gases in the UTLS is probably misrepresented in models by about as factor of two. This has important implications, for example, for the calculated lifetime of aircraft exhausts and ozone changes in the extra-tropical lower stratosphere. HALO would enable wide-ranging coverage of the UTLS region from the subtropics to the poles. HALO would be unique in providing the flight range to perform case studies of synoptic weather systems (i.e., fronts and cyclones with a scale of ~1000 km) that control the cross-tropopause exchange processes. HALO could systematically sample the UTLS region, required to quantify chemical processes as well as dynamical transport and mixing across into and within the UTLS, required to quantify chemical and transport processes, through the measurement of chemical tracers, coupled to meteorological information available from the European Centre for Medium-range Weather Forecasts.

Reducing the uncertainty about the amount of lightning produced nitrogen oxides

Tropospheric photochemistry depends strongly on ambient levels of nitrogen oxides (NO_x). Lightning in deep convective clouds contributes considerably to the global NO_x

budget, in particular in the tropics. Present estimates of the global lightning NO_x source range from 1 to 20 Tg(N)/yr. Using the best estimate of 5 Tg(N)/year, models compute that lightning contributes about 80% to the NO_x abundance in the upper tropical troposphere. At present there are no in-situ measurements of NO_x in the upper tropical troposphere at altitudes above 12 km. Measurements with HALO along the oceans downwind of the continents, where most convection occurs, will help determine the NO_x -lightning relationship and strongly reduce the uncertainty of source estimates. Improved knowledge of the lightning NO_x formation rate is needed, e.g., to assess the importance of growing anthropogenic sources. For instance, aircraft emissions presently contribute about 0.8 to 1 Tg(N)/yr to the NO_x budget, less than lightning.

2. Atmospheric Dynamics and Transport

Uncovering stratosphere-troposphere coupling

Recently, the role of the stratosphere in the control of weather and climate in the troposphere has taken an unexpected turn. The stratospheric ozone layer is quite sensitive to variations in solar and cosmic radiation. Dynamic coupling between the stratosphere and troposphere (ST) may provide an amplifying feedback that links climate variability to the influence of the Sun. This ST coupling has been substantiated for climate change during the Holocene through measurements of cosmogenic nuclides. Quantifying the relevant ST feedbacks will even improve seasonal weather forecasting, in particular in the North Atlantic region and adjacent continents. Furthermore, ST-exchange is a major source of ozone to the troposphere, and thus also plays an important role in the OH cycle, however, the uncertainties in flux estimates are very large. Improvement will help quantify the tropospheric ozone budget. Dynamic ST coupling can be studied by measuring long-lived trace gases in the lower stratosphere, a region that would be reached by HALO. Other aircraft cannot reach the stratosphere, or in the case of the American ER2 and Russian Geophysica aircraft (that reach 21 km), cannot carry large payloads and operate in the turbulent tropopause region (e.g., along the jet stream).

Quantifying transport effects of deep convection

Deep thunderstorm convection is a main tropospheric mixing mechanism, exchanging heat, momentum, water vapour and reactive species between the lower and upper troposphere. Deep convective clouds are moreover the main precipitation source in the tropics and subtropics. Firstly, satellite measurements have indicated that pollutant aerosols, e.g., from biomass burning in the tropics, can modify convective clouds to the extent that precipitation formation and lightning are considerably changed. Satellite observations however are limited to the upper parts of clouds, and it is well-known that these parameters vary with altitude. HALO would enable measurements over the entire cloud depth up to 15 km. The observed cloud and aerosol microphysical parameters could thus be linked to satellite measurements. Secondly, convective outflow includes gases and aerosols that interact with ice clouds, a topic that has only recently been explored. Thirdly, tropical convection plays a key, yet poorly understood role in drying the stratosphere, e.g., through freeze-drying of the tropical tropopause. In fact, the lower stratosphere appears to have moistened relatively rapidly in the past decades, and the cause is unclear. Finally, a several kilometre thick tropical transition layer above 13 km altitude has been discovered recently. Transport processes across this layer and the role of convection are currently debated. In contrast to currently available aircraft, HALO could perform the needed measurements even at the cloud tops and in the convective outflow region, which would help resolve these important issues.

Measuring intercontinental pollution transports

In the extra-tropical free troposphere (up to about 13 km altitude) hemispheric pollution transport is often fast, with wind speeds exceeding 100 km/hr. This implies that trace species with a lifetime of about a week or more can be distributed hemispherically. Although pollutant emissions in Europe and North America have been reduced with some degree of success, emissions from other regions grow largely unabated. In the northern hemisphere the following picture emerges. Through the prevailing westerly winds, emissions from the USA contribute in particular to the background pollution levels in Europe, for example, of ozone and carbon monoxide (lifetime 1-2 months). Europe on the other hand exports part of its pollution toward Asia. In Asia, rapidly growing pollution emissions from a population of several billion are observed, particularly in association with emerging economies in the south and east. The large emission sources west and east of the North Atlantic and North Pacific Oceans contribute to intercontinental plumes that affect air quality and climate on a hemispheric scale. In the southern hemisphere similar large-scale pollution transports can occur from savannah and forest fires during the dry season, e.g., in southern Africa and South America. HALO would provide the aircraft needed, i.e., the platform with a global range to determine pollution transports with a global dimension.

3. Cloud Research

Improving the understanding of cirrus clouds

Ice clouds in the upper troposphere play an important role in the climate system. For example, an increase of cirrus clouds under climate change conditions would contribute to a warming tendency that may amplify the effect of increasing greenhouse gases. Cirrus microphysical and radiative properties are nevertheless poorly quantified. Influences of pollutant aerosols on ice crystals and the lifetime of cirrus, including aircraft condensation trails, are potentially very strong. In addition, the cirrus representation in weather forecasting models needs to be improved based on observations. This has the potential of substantially improving medium- to long-range weather forecasts. A major improvement is needed in the observation of cirrus crystal size. Size dependent sedimentation of cirrus often determines the onset of precipitation. Furthermore, heterogeneous reactions between cirrus ice and gases involved in ozone chemistry, similar to polar stratospheric clouds, have been speculated about; hence in situ measurements are urgently needed. Redistribution of water vapour, aerosols and dissolved gases through the sedimentation of ice crystals is another unresolved issue. HALO would provide the measurement capability to reach the upper troposphere with comprehensive instrumentation, required to facilitate cirrus cloud research.

Providing crucial cloud data for reducing uncertainty in climate modelling

The present capability of quantifying climate change, including scenario studies of future developments, suffers from uncertainties in representing cloud effects in climate models. State-of-the-art-models predict a cloud radiative forcing feedback at the top of the atmosphere ranging from –1 to + 2 W/m^2 for a doubling of CO_2. This uncertainty must be reduced for more reliable climate modelling. Together with satellite and ground-based observations HALO would provide data sets that can be used to test and improve cloud models, which can subsequently be used to advance the cloud representation in climate models. Case studies are needed, in particular of tropical cloud systems, for which the three-dimensional cloud fields can be quantified (geometry, liquid and ice water content, and vapour distribution) and the reflected solar and outgoing infrared radiative fluxes above the cloudy atmosphere determined. Such data sets, combined with data from satellites and ground based remote sensing, would help to improve models and hence to reduce the uncertainty of climate change predictions.

4. Meteorological Research

Improving weather forecasting

Numerical weather forecast models have improved significantly the prediction of several key parameters over the past ten years, including temperature, wind, and even cloud cover. No progress has been made, on the other hand, in the prediction of precipitation, indicating that essential cloud processes are still poorly understood and parameterised in models. The basic problem in the understanding and prediction of cloud processes lies in the fact that clouds are multi-scale, multi-process, multi-phase systems in which interacting microphysical, dynamic, chemical and radiation processes need to be understood. Convective systems, in particular, are extensive, highly complex three-dimensional systems with crucial roles in the global water cycle, global energy balance and the vertical transport of trace substances. The development of improved cloud parameterisations and sufficient constraints on complex cloud models require the acquisition of comprehensive multi-disciplinary and highly resolved in situ data sets that reach from the aerosol (gases + particles) input and precipitation output in the planetary boundary layer (PBL) via a large number of cross sections at different cloud levels to the aerosol output near the tops of convective systems. Only a research aircraft such as HALO with large payload, long and effective endurance from the PBL to the tropopause region can fulfil this task.

5. Climate Research

Closing the energy budget of the atmosphere

Atmospheric absorption is a key component in the energy budget of the atmosphere. To date this parameter is determined from satellite and ground based radiation measurements. These data rely on an inadequate mixture of satellite and surface results. Significant discrepancies exist between modelled and experimentally derived radiation balances. To resolve this problem, internally consistent radiation data sets covering the full atmospheric wavelength range are required over the complete tropospheric column. For the deployment of the adequate radiation payload a large capacity and long endurance, high ceiling airborne platform such as HALO is urgently needed. German radiation research has the critical mass to develop the necessary HALO instrumentation, its deployment and also for the interpretation of the results with state of the art radiation models.

Narrowing uncertainty in climate system sensitivity

Since 1990, little progress has been made in assessing the global-mean near-surface temperature increase predicted as a consequence of an enhanced greenhouse effect. The range still given (1.5 to 4.5K for a doubling of CO_2 concentration) can be narrowed mainly through better parameterisations of cloud processes in climate models. Major unknowns are the dependence of tropical anvil cloud microphysics on surface temperature and aerosol characteristics and the precipitation formation in areas with intense convection in cold air outbreaks over remote ocean areas with strong horizontal sea temperature gradients. For both mission types, a high flying and long endurance aircraft is needed. Another key issue for climatology is the search for the negative feedback mechanism that keeps the greenhouse effect of the Earth in rather narrow bands (± 5K) over many million years. The hypothesis that it is due to microphysical cloud processes that are influenced by emissions from the terrestrial and marine biosphere can be proven or falsified only if satellite sensors (e.g., Earth Care) are combined with HALO missions.

6. Global Carbon Cycle

Estimating biospheric and oceanic carbon uptake

There are three large sinks among which anthropogenic CO_2 is being partitioned: the atmosphere, the oceans, and the terrestrial biosphere. While the atmospheric and oceanic carbon reservoirs are quite accurately known, the terrestrial sink remains very difficult to quantify. In particular, attempts to measure uptake of CO_2 by the Amazon forest using eddy covariance (EC) techniques have resulted in estimates ranging from 0 to 5 Pg C per year, a range so wide as to make these estimates meaningless. Hence alternative measurement methods are needed. HALO would make two alternative approaches feasible: First, the use of airborne eddy covariance, which would remove the spatial bias suspected in the tower-based EC measurements, and allow measurements over more representative spatial scales. Second, HALO would also make possible the large-scale application of the boundary layer (BL) budget techniques, which are based on an analysis of the temporal and spatial distribution of CO_2. These techniques essentially determine the amount of CO_2 removed from the BL by photosynthesis and the amount added to the BL by respiration during the diurnal cycle. The long endurance of HALO would enable CO_2 profiling over a complete diurnal cycle, something that has not been possible so far because of the limitations of current aircraft. HALO would also permit Lagrangian or quasi-Lagrangian experiments, where the BL budget of CO_2 is followed in an air mass over several days.

Performing high latitude climate change and carbon cycle research

Climate change, as induced by increasing greenhouse gases, is predicted to lead in particular to the warming of boreal regions, in part associated with the high-latitude ice-albedo positive feedback. Over the last three decades, rapid climate change has been observed in Siberia and Alaska, reaching warming rates as high as 1ºC per decade. Such change will affect permafrost, which underlies 25% of the land surface in the northern hemisphere. Modelling studies suggest a 15% reduction in the permafrost area by the middle of this century. An additional major positive climate feedback at high latitudes is that permafrost thawing will release carbon dioxide and methane, and alter the vegetation and surface hydrology. The massive amounts of carbon stored in high-latitude soils (peats) can have a pronounced impact on the atmospheric CO_2 burden, even if only a modest fraction is released as a consequence of climate change. Another important aspect is that about a third of the past and present anthropogenic CO_2 emissions may be re-assimilated by the terrestrial biosphere. It has been speculated that either the North American or Eurasian continents play an important role, while others claim that the tropics are important. The present dramatic warming rates in the boreal zone, caused by anthropogenic effects or natural climate fluctuations, offer a unique opportunity to study the response of the biosphere to a changing climate. The lessons from these investigations will be central to predicting and mitigating the effects of climate change on the biosphere.

As part of an integrated research program, these issues would be studied with HALO by performing long flight tracks over the Siberian forests and tundra's, measuring CO_2 and CH_4 fluxes and evaporation by combining high-resolution concentration and 3D wind measurements. In addition, carbon isotopes will be measured to help identify sources and sinks.

7. Polar Research

Observing changing Arctic sea ice thickness and distribution

Fluxes of energy, mass and momentum between the polar ocean and the atmosphere are strongly influenced by the thickness and extension of sea ice. The development of climate models as well as regional polar forecast models requires detailed information about the sea ice extent. Especially for the summer and marginal sea ice zones the presently available information is insufficient. The prediction of sea ice, important for example for high latitude ship traffic, is only possible if the initial state of the ice is known with high accuracy and resolution. Furthermore, sea ice thickness is an important parameter in climate change detection, in particular because climate change is expected to be relatively strong at high latitudes. In the past decade, ice data have been collected mainly from satellite passive microwave sensors with a spatial resolution of about 25-100 km. Some case studies have aimed at higher resolution, including recent measurements from submarines with upward looking sonars. Previously, measurements with small aircraft have been performed as well, however, the operational range was restricted to 300-400 km. HALO would help quantify Arctic sea ice properties at high spatial resolution, improve dynamic sea ice models based on aircraft measurements, and contribute to high-latitude climate change detection. This includes the inner Arctic region, which has yet hardly been explored.

Detecting Arctic air pollution

Arctic aerosols and trace gases play an important role in polar air pollution and climate change, in particular during springtime “Arctic haze”. The specific conditions in the Arctic (aerosol composition, transport altitude, surface albedo, long radiation paths through the atmosphere) are complex and poorly understood. It is for example unclear if the aerosol pollution contributes to a cooling or a warming tendency of the surface and lower atmosphere. The Arctic Ocean furthermore contributes to atmospheric chemistry through the release of organohalogens from algal blooms. Subsequent release of reactive halogen compounds at the ice surface through heterogeneous processes leads to tropospheric ozone depletion events. At higher altitudes, i.e. in the stratosphere, ozone depletion is caused by anthropogenic halogen compounds, mediated by polar stratospheric clouds (PSCs). Recently "giant" ice particles have been discovered in the Arctic stratosphere, of which the formation and role in ozone depletion are yet unclear. Additional uncertainties regarding future recovery of stratospheric ozone involve PSC formation and the role of bromine compounds, especially if recent downward temperature and upward water vapour trends continue into the future. HALO would be able to deeply penetrate the Arctic stratosphere as well as the troposphere toward the pole to determine ozone destruction and quantify climate effects of Arctic aerosols.

8. Earth Observation

Searching for signatures of terrestrial impacts of extraterrestrial objects

Impacts of extraterrestrial objects on Earth have been recognised as a major factor in geological history. They have also triggered regional and global climate effects. The impacts of large asteroids or comets have significantly shaped the surface and the structure of the Earth’s upper crust. They had enormous impact on the evolution of the biosphere and, therefore, were of first order relevance for the evolution of life on Earth. The records of extraterrestrial impacts is still being deciphered. They should be statistically equally distributed on surfaces of the same geological ages. However, the mapped terrestrial impacts on Central Africa, Siberia and South America suggest less impacts in these regions than over the rest of the world. This wrong image, however, is mainly generated by the lack of suitable geophysical and geological data, e.g. gravity field data. HALO would be an ideal platform for searching impacts sites over these poorly accessible regions of the globe because of it's long-range and high-speed cruising performance. Large impacts can be better detected by a combination of aerogravimetric and aeroemagnetometric sensing systems. HALO would provide the opportunity to operate such large instrument payloads – in combination with other Earth observation instruments – during long-range missions over remote areas of the globe.

Geomorphology and land-use changes

Natural and anthropogenic processes of Global Change may cause substantial changes in land-use and vegetation cover, in particular in the tropical regions. They are generally accompanied by processes such as soil erosion or land degradation that are e.g. triggered by biomass burning. Of particular importance for an assessment of the geomorphological and geoecological effects of such changes is the quantification of their temporal evolution, i.e. the rate change. Digital processing of photo images obtained from airborne and space- borne platforms is a suitable technique to investigate and monitor surface pattern and surface dynamics and their variation. HALO would provide the opportunity to collect multispectral photo-images with spatial resolutions that fill the gap between low-scale satellites images and high scale images obtained from small aircraft or small tethered balloons. Due to it's long-range performance at altitudes up to 14000 m HALO would be an ideal tool for systematic studies of the 'nested scales' of these changes, in particular over remote regions of the globe for which even conventional images are not available.

9. Earth gravimetry and GPS navigation

Bridging the gap between satellite and surface gravity

Just recently, a new stage of gravimetric and magnetometric earth observation has been entered. CHAMP is operative since 18 months and a complementary mission will be launched in March 2002: GRACE. CHAMP observes the gravity and magnetic field, GRACE and another ESA mission, GOCE, will measure the gravity from space with yet unprecedented precision and coverage. The results of these missions will be combined with existing and upcoming satellite altimetry data over the oceans. Yet, there is no such data set to fill in the gap between surface and spaceborne gravity measurements over the continents. This gap in wavelengths and amplitudes could be filled in using HALO as a platform for aerogravimetry and aeromagnetometry observations. Especially over South America (Andes), Africa (East African Ridge System), the Near East (Dead Sea Rift) and Asia (Himalaya), HALO could easily cover large areas of missing or possibly doubtful data (terrain correction problems). Also large marine areas lacking high density data coverage could be monitored with HALO’s capabilities in range and speed. Such aerogravity programs would not only contribute to a much more detailed geoid (and precise navigation) but also to a much better understanding of main geophysical processes and driving forces.

Enhancing GPS, navigation and cockpit guiding tools

HALO would be an excellent test bed for university and industry research on the next generation of GPS systems. Online kinematic GPS tracking from satellites only, without using fixed ground reference systems, could be tested in different environmental settings using various sets of receivers and frequencies. Already now, the industry offers GPS receivers with kinematic positioning on 10 Hz and soon on 20 Hz data rates. Using antenna arrays on HALO, heading, pitch and roll could be computed from GPS only. The radio link of HALO might as well be used to test new cockpit information systems for "roll-over" weather forecast systems as well for the detection of ionospheric disturbances using magnetometers on-board and off-ground. Other GPS techniques as GPS altimetry and especially limb-sounding in the higher atmosphere are challenging targets that could be tackled using HALO as an experimental platform.

II.1.b) Services

The concept behind HALO is to provide an optimal platform for airborne atmospheric science and Earth observation, a well-equipped flying laboratory that allows the scientists onboard to completely focus on their own experiment. The projected range of associated services builds on the experience gained during numerous campaigns on the existing research aircraft fleet in Europe, and particularly at DLR. It represents the combination of the existing status quo and the additional user demands resulting from this experience.

A large set of jet aircraft candidates was investigated. It was found that only two types of business jet aircraft would satisfy the requirements: the Gulfstream V and the Global Express. All other aircraft suffer from smaller range, ceiling and load capability. Some business aircraft with triple engine propulsion provide additional constraints. The possibility that equipment mounted on the roof of the aircraft, or ice accreted to such equipment, could break off and damage the top-mounted engine would severely reduce the kinds of probes that could be installed on top of the aircraft.

The aircraft of the type Gulfstream G V of the American Gulfstream Aerospace Company (General Dynamics) and the Global Express (GE) of the Canadian company Bombardier satisfy the essential requirements:

- range well above 8000 km or more than 10 flight hours for transcontinental experiments and long duration measurements;
- certified ceiling of more than 15 km,
- maximum payload of 3 tons,
- a large usable cabin area of 20-30 m^2 for simultaneous operation of several complementary instruments and scientific personnel from several groups (for multidisciplinary and international projects),
- potential for quick modifications for a wide variety of applications and for flexible use as research aircraft with different instrument configurations for various research projects.

Both aircraft are well established in the market and available globally. They offer high operational reliability. In case of technical problems the manufacturer and the system suppliers provide services world-wide. Both aircraft have been presented by the manufacturers to the Flight Facility and users at DLR Oberpfaffenhofen in 2001. The flight performance of both aircraft up to 51000 ft has been presented in a prescribed flight manoeuvre sequence. During presentations, the specification requirements for HALO were presented by DLR and discussed in detail with engineers of the manufacturers. The discussions confirmed that both aircraft types satisfy the expected user requirements. Both aircraft use German engines for propulsion.

Owing to its unique characteristics HALO would be able to offer many features that the present aircraft are simply not able to fulfil. The proposed range of services covers also many items that are not directly associated with the aircraft itself, but includes items like experiment preparation or the provision of aircraft and sensor data. Therefore, the choice of the associated infrastructure and aircraft operator is of crucial importance for this concept.

To be a suitable platform for environmental research, HALO would have to provide certain mechanical and electronic interfaces that need to be added to the basic aircraft. These modifications of the aircraft frame, electronics, avionics, and sensor systems are prerequisite to operate any scientific instrumentation on HALO. In order to simplify the transfer of existing scientific equipment, it is planned to copy many standard interfaces from the most popular research aircraft in Europe, such as the DLR Falcon.

HALO would carry a basic sensor package and data acquisition system to provide a complete set of meteorological and aircraft data to each user. The envisaged standard sensor package on HALO would be more complete than the ones on the present research aircraft and it will use new sensor concepts and better sensor equipment. It is expected that the aircraft operator would be able to operate and calibrate these sensors and that on-site data processing during a campaign can be provided.

HALO would carry a satellite communication system with world-wide coverage on board of a research aircraft for communication and data transmission. The availability of data on the ground and the possibility to communicate with the aircraft world-wide and online would allow completely new concepts in operating the aircraft and increase its efficiency. This feature could also be used for educational purposes. It is also planned to provide associated services like certification and installation of user equipment on the aircraft, logistics, campaign support and aircraft sensor data evaluation by the aircraft operator.

II.1.c) Main Strengths and Weaknesses

HALO would provide the opportunity to carry out measurements in areas that can currently not be probed by other platforms. This includes nearly the full altitude range of the troposphere and lowermost stratosphere, as well as remote parts of the Earth. It could carry comprehensive payloads for simultaneous observation of a large set of species. It would be the first European research aircraft with these specifications and under these flight operation conditions.

The main strengths of the proposed HALO aircraft would be its long range and endurance, high ceiling altitude and large instrument load capacities, which are not available in such combination on any other research aircraft. It would use existing technology for the base aircraft and include modern instrumentation. Further strengths of the aircraft would be its flexible operational constraints, i.e., it could use most of existing airfields.

Weaknesses and shortcomings are due to the limitations: Ideally one would like to have an aircraft with more than 20 km altitude range, 10 tons of scientific load, global range, and fully flexible operations. However such an aircraft does not exist, and even if it did, would be far more expensive than HALO. The unavoidable limitations of any feasible research aircraft will be overcome by combining this research tool with other, more specific platforms.

II.1.d) National and International Networks

The new research aircraft would be used within various ongoing and similar future research projects. On national German level these programmes include:

- AFO 2000 of BMBF: Atmospheric Research;
- DEKLIM of BMBF: Climate Variability and Prognosis;
- HGF: Concept of the section „Atmosphäre und Klima“ and „Erdsystemforschung“ within the research area „Erde und Umwelt“ of the HGF-programme.

For the community of university institutes there are plans to set up a special research area on research topics that can be addressed with HALO within the Deutsche Forschungsgemeinschaft (DFG).

On the international level several research programmes have been defined to which the research with HALO would contribute. These include programmes that are part of the International Geosphere-Biosphere Programme (IGBP) and the World Climate Research Programme (WCRP):

- IGBP/IGAC: International Global Atmospheric Chemistry Project;
- WCRP/GEWEX: Global Energy and Water Cycle Experiment;
- WCRP/ACSYS (Arctic Climate System Studies) and the follow-up programme WCRP/CLIC (Climate and Cryosphere);
- WCRP/SPARC: Stratospheric Processes and their Role in Climate.

The future German contributions to Global Change research are centred on the concept of Earth System Science. According to DLR this research for its observational dimension would strongly benefit from or even require an aircraft such as HALO.

The proposal of the European Commission for the 6th RTD Framework Programme contains a thematic area *Global Change,* which requires research of the kind to be performed with HALO. The programme foresees research priority lines “Impact and mechanisms of greenhouse gas emissions and other atmospheric constituents on climate and carbon sinks (oceans, forests and soil)”, ”Water cycle”, and “Global climate change observing systems”.

Further European projects under preparation include the new EUROTRAC-2 Projects TROPOSAT (The Use and Usability of Satellite Data for Tropospheric Research), an extension of EXPORT (European Export of Precursors and Ozone by Long-Range Transport), and plans for a COST-action on the Upper Troposphere and Lower Stratosphere.

II.1.e) Enlarging / Upgrading

An extension of the period of operation beyond the first six years of operation is highly desirable. Based on the experience from similar research facilities it is conceived that HALO should be in use for a long period (of the order of 25 years).

The need for further investments into instruments and further modifications of the aircraft may arise during the first six years of operation, and even continue after this period.

After an initial operation period with testing of all HALO components, the HALO aircraft might be used for long-range research experiments. In the course of these experiments it might turn out that the number of flight hours (440 hours) envisaged so far is not enough, so that an extension of this part might be requested. Financing should be assured by international users or BMBF.

II.2. Transfer of Research Results

The utilisation aspects of knowledge gained within the HALO project are difficult to foresee in detail, as they will partly depend on the specific results of future missions with this platform. However, some general expectations are:

Research with HALO would improve the knowledge about aircraft emissions and their dispersion in the atmosphere. Experience from past research shows that the aviation industry benefits from such knowledge which guides the development of less emissive and more efficient aircraft engines.

The sensor industry involved with the development of satellite sensors would directly benefit from the possibility of using a high-flying aircraft for prototype testing. Furthermore, the development of new sensor systems within the research institutions would spark cooperation with and innovation transfer to the sensor industry.
Atmospheric research using HALO would also help in improving operational weather forecasts, extending these beyond the medium range, as well as climate predictions on relatively short time scales (for example the "El Niño" phenomenon). This has obvious benefits for a wide range of business sectors and the economy as a whole.

Generally, the HALO project would provide a better understanding of the Earth-atmosphere system. This knowledge would serve as basis for assessing global change and helps making informed economic and political decisions. As a prominent example, scientific knowledge about the Earth-atmosphere system has led to the Montreal and Kyoto protocols regulating anthropogenic emissions of a large number of greenhouse or ozone-depleting gases. In some cases the chemical industry has reacted promptly by developing less harmful replacements for gases regulated by these protocols. By providing input to political and economic decisions the HALO project would contribute to the preservation of our ecosystem and to a sustainable economic development. New market aspects may arise for new applications also outside the research area. More generally, the HALO aircraft would enhance international cooperation beyond science in all respects. This might also lead to enhanced economic cooperation and market developments.

The transfer of scientific knowledge to policy makers, industry, and the general public, would occur in the form of contributions to scientific assessment reports as well as HALO-dedicated reports, press releases or articles. In addition, the organisations carrying HALO (DLR, MPG and others) offer specific support in innovation transfer to industry.

Spin-offs are to be expected from the instrument developments and from the application projects, but are hard to foresee.

A.III. The Institutions participating in the Project

The proposal is submitted by MPG and DLR on behalf of a number of universities and research institutes. The following table lists the participating institutions and their research topics of interest.

Institute	below: Institute name. right: Short descriptor of the research topics: C: Chemistry and Transport, S: Stratosphere, B: Bio-sphere, K: Convection, P: Precipitation, O: Ocean and Ice, T: air traffic and traffic-meteorology, E: Earth observa-tion, R: Remote sensing	Research Topic								
		C	S	B	K	P	O	T	E	R
AWI	Alfred-Wegener-Institut für Polar- und Meeresforschung, Fachbereich Klimasystem, Bremerhaven	x	x	x	x	x	X	x	x	x
DLR, DFD	Deutsches Zentrum für Luft- und Raumfahrt, Deutsches Fernerkundungsdatenzentrum, Oberpfaffenhofen		x	x					x	x
DLR, IMF	Deutsches Zentrum für Luft- und Raumfahrt, Institut für Methodik der Fernerkundung, Oberpfaffenhofen		x				x		x	X
DLR, IPA	Deutsches Zentrum für Luft- und Raumfahrt, Institut für Physik der Atmosphäre, Oberpfaffenhofen	X	x	x	X	x		X	x	X
DLR, IWP	Deutsches Zentrum für Luft- und Raumfahrt, Institut für Weltraumsensorik und Planetenerkundung, Berlin		x							
DWD	Deutscher Wetterdienst					x				x
FhG, IFU	Fraunhofer Institut für Atmosphärische Umweltforschung, Garmisch-Partenkirchen	X		X				x	x	X
FZJ, ICG	Forschungszentrum Jülich, Institut für Chemie und Dynamik der Geosphäre	X	X	x	X		x	x		x
FZK, IMK	Forschungszentrum Karlsruhe, Institut für Meteorologie und Klimaforschung, Karlsruhe	x	X		X			x	x	X
GFZ	Geoforschungszentrum Potsdam									X
GKSS, IAP, IfK	GKSS Forschungszentrum Geesthacht GmbH, Institut für Atmosphärenphysik und Institut für Küstenforschung	X		x	X	x		x		x
IfT, WGL	Leibniz-Institut für Troposphärenforschung, Leipzig	x		x	x	X		x		
MPIB	Max-Planck-Institut für Biogeochemie, Jena			X	x				X	x
MPIC	Max-Planck-Institut für Chemie, Mainz	X	X	X	x	x		x	x	x
MPIK	Max-Planck-Institut für Kernphysik, Abteilung Atmosphärenphysik, Heidelberg	X	X	x		x		X		
MPIM	Max-Planck-Institut für Meteorologie, Hamburg	x	x	x	X	X	x	x	x	x
PIK, WGL	Potsdam Institut für Klimafolgenforschung, Potsdam			x					x	
TU Mü, LBI	Lehrstuhl für Bioklimatologie und Immissionsforschung, Technische Universität München	x		x	x			x		
TU Mü, IWC	Institut für Wasserchemie, Technische Universität München	x		x				x		
UniBo, MIUB	Meteorologisches Institut, Universität Bonn			x	x	x				x
UniBr, IUP	Institut für Umweltphysik, Universität Bremen/FB1	X	X	X	x	X		x	X	X
UniF, IMG	Institut für Meteorologie und Geophysik, Johann Wolfgang Goethe-Universität, Frankfurt	X	X		x	x		x	x	X
UniF, IPG	Institut für Physikalische Geographie, Johann Wolfgang Goethe-Universität, Frankfurt			x					X	
UniF, ZUF	Zentrum für Umweltforschung, Johann Wolfgang Goethe Universität, Frankfurt	x			x	x		x		
UniHa, IMK	Institut für Meteorologie und Klimatologie							x		

Institute	below: Institute name. right: Short descriptor of the research topics: C: Chemistry and Transport, S: Stratosphere, B: Bio-sphere, K: Convection, P: Precipitation, O: Ocean and Ice, T: air traffic and traffic-meteorology, E: Earth observa-tion, R: Remote sensing	Research Topic								
		C	S	B	K	P	O	T	E	R
	der Universität Hannover: (Thema: Verkehrsmeteorologie)									
UniHam, MI	**Meteorologisches Institut der Universität Hamburg**				X	X	X		X	
UniHd, IUP	**Institut für Umweltphysik, Ruprecht-Karls-Universität Heidelberg**	x	x						x	X
UniKa, IMK	**Institut für Meteorologie und Klimaforschung, Universität Karlsruhe**	X			X	x				
UniKö, IMK	**Institut für Geophysik und Meteorologie, Universität zu Köln**	x	x		x	x		x	x	
UniL, IM	**Institut für Meteorologie, Universität Leipzig**	x	X		x	X				X
UniMa, IPA	**Institut für Physik der Atmosphäre, Johannes Gutenberg-Universität Mainz**	x	x	x	x	x		x		x
UniMü, MIM	**Meteorologisches Institut München der Ludwig-Maximilians-Universität, München**				x	x				x

DLR would operate the aircraft at its research site in Oberpfaffenhofen. This operation would be based on the competence of the DLR Flight Department , with facilites at the airports in Oberpfaffenhofen and Braunschweig. The DLR Flight Facility's competence is strongly enhanced by direct cooperation with the research institutes of DLR, in particular the Institute of Atmospheric Physics (IPA) and other institutes (Institute of Remote Sensing Technology, German Remote Sensing Data Centre, Institute of High Frequency / and Radar Technology) of DLR at Oberpfaffenhofen. Moreover the DLR know-how derives from the experience and contributions in the fields of space and airborne research in a total of 31 institutes of DLR in Berlin, Braunschweig, Cologne, Göttingen, and Stuttgart, besides Oberpfaffenhofen. DLR would perform this task in close cooperation with all other HGF institutes.

MPG would contribute leadership in organising the science program performed with HALO, its instrumentation, and support its use through workshops. Obviously, this coordination would be performed in close cooperation with all other scientists interested in the use of HALO. MPG would perform this task based on the competence of several Max Planck Institutes (MPI), represented by the MPI for Chemistry in Mainz, and strongly supported by the MPI for Meteorology in Hamburg, and the MPI for Nuclear Physics (Atmospheric Science Group), and, in specific research projects, the MPI for Biogeochemistry in Jena.

The HGF institutes in Bremerhaven, Jülich, Karlsruhe, Geesthacht, and Potsdam all have strong competence in airborne research. Bremerhaven concentrates on polar research, Jülich and Karlsruhe together with Oberpfaffenhofen and Geesthacht on various aspects of atmospheric sciences, Geesthacht on coastal research and Potsdam on Earth System Sciences. All these HGF institutes provide complementary facilities and instruments for airborne research.

The Fraunhofer Institute of Environmental Research in Garmisch-Partenkirchen has much experience in atmosphere-biosphere interaction and sounding of the atmosphere, e.g., from the Zugspitze, and will be merged with the Forschungszentrum Karlsruhe in 2002.

The proposal is also strongly supported by institutes of the WGL, in particular the Leibniz-Institute for Tropospheric Research in Leipzig, with much experience in airborne research. Other WGL institutes at present include the Potsdam Institute for Climate Impact Research in Potsdam, and possibly also the Institute of Atmospheric Physics in Kühlungsborn.

A.IV. Users of the Facility

Research in the following disciplines cannot be adequately performed without having access to research aircraft:

- Atmospheric sciences, (atmospheric physics and chemistry, including or overlapping with biogeochemistry, geophysics, meteorology and climate research),

- Earth observation in connection with polar research, oceanography, geography, ecology, glaciology and environmental research in general.

Research aircraft are also a prerequisite for development and testing of remote sensing, telecommunications, high-frequency technology and radar technology, and aerospace applications.

The facility is of central importance in particular for research on the atmospheric composition in the upper troposphere and lower stratosphere and for measurements in remote regions. There are many atmospheric parameters (for example concentrations of trace species and cirrus particle morphology), which cannot be measured with the required accuracy and resolution by other means. It will be impossible to design innovative experiments in, e.g., the tropics or over the polar regions without having access to a long-range research aircraft.

Since the early 1990s, the participation by external users from all over Europe has grown considerably, in particular because of joint German and European Research programmes with funding from the EC and BMBF. The DLR itself strongly supported this cooperation by participation and coordination of several related infrastructure and research programmes. Still, the support available for operations is often limited and a constraint for cooperation, in particular with German university institutes. Moreover, the Falcon is too small to accommodate cooperation of a larger team of instrument-scientists from various institutes.

As a consequence of the HALO concept (larger aircraft and support for operations) the participation of non-DLR users of the HALO aircraft will be much larger than for the Falcon. It will in particular facilitate university research projects.

The HALO aircraft would be operated under the following conditions: The facility would be open to "external" as well as "internal" scientific users under equal conditions, as controlled by a scientific advisory committee established by the sponsoring agencies. The HALO aircraft would be open in principle to all earth sciences and other science disciplines requiring access to a research aircraft with the specifications offered by HALO. HALO would enable innovative interdisciplinary and international research, which requires the availability of a high flying, long range, high load-capacity, well instrumented research aircraft (the conditions are meant to apply in one or several combinations). Users, whose requirements can be satisfied with a small or short-range aircraft will be asked to consider other facilities. This would not exclude the use of HALO aircraft in smaller missions or test missions to test new or changed instrumentation or to test certain measurement procedures before a major research mission is performed that requires the entire capacity of HALO. Users would be selected on the basis of research proposals, after expert review, based on quality and costs of the proposed research project and suitability for HALO. It is expected that most projects would be performed by a consortium of scientists from various institutes and various nations.

Scientists from universities would have access to the HALO aircraft in all respects and at equal conditions. They would be encouraged to use HALO also for education purposes (within doctoral and diploma thesis works), and this might imply that occasionally small mission would be carried out. The scientific advisory committee would have at least one member representing the university users.

IV.1. Scientific Education

The HALO aircraft would play an important role in training and furthering the future generation of scientists. Field campaigns with aircraft are very attractive to students, because they enable them to learn directly from measurements during real atmospheric conditions. From experience it is known that such experiments fit excellently within the time frame of doctoral and diploma (PhD and Master) theses. Within a doctoral project a student may conceive (together with his or her advisor) the details of a new experiment, develop or modify the instruments and the operations, perform the experiment by flying him/herself as scientific observers on board the aircraft, record and evaluate the data, and finally publish the analysed results. The airborne part of such a mission is also very well suited for a diploma theses.

The DLR Flight Facility will apply for European Commission (EC) programs that support access to unique infrastructures. Since 1995 the EC supports special access programs for large-scale facilities in environmental research within the 5th (TMR) and 6th (IHP) framework programs. The DLR Falcon and its related infrastructure has been funded in the two previous “Access Projects”, STAAARTE (Scientific Training and Access to Aircraft for Atmospheric Research Throughout Europe) and CAATER (Coordinated Access to Aircraft for Transnational Environmental Research). These access programs enable European scientists to get acquainted with this type of infrastructure, including training and a full user service. These projects are expected to be continued as part of future EC framework programs.

For six years the DLR Flight Facility, triggered by the above EC access programs, has offered a special novice training course that has been set up for the Falcon to show the possibilities of aircraft use, available sensor systems, flight operations and associated limitations, campaign management and scientific guidance of multi-aircraft missions, mission logistics, sensor system installation, sensor system certification, aircraft interfaces, on-board data acquisition and processing units, post-flight data processing etc. A scientist of the DLR Flight Facility acts as “facilitator” to guide the inexperienced user through the EU access programs. This service is rather unique in Europe and it could easily be adjusted to accommodate HALO users. Furthermore, during the modification and establishment phase of HALO there would be some good opportunities for students from technical universities to work on diploma theses.

An additional initiative is the establishment of an International Max Planck Research School (IMPRS) for Experimental Atmospheric Chemistry and Physics to address regional and global atmospheric change. The IMPRS will support the education of graduate students through grants, colloquia and specialised courses. The graduates would be actively involved in the development of sensitive and fast response instrumentation, and in field measurement campaigns with HALO to study chemical and physical processes within the atmosphere. The initiating partners of the IMPRS are the MPI for Chemistry and the Universities of Mainz, Heidelberg and Frankfurt. Active collaborations furthermore include a large number of universities and research institutions in Germany (including the DLR), several other European countries and the USA. The IMPRS aims to contribute to a stimulating and internationally oriented environment for high quality research and education. It will support university teaching programs through specialised courses, student exchanges, interactive international video lectures, workshops and e-learning through the Internet. Students from developing countries can also participate in the training program and can apply for research opportunities. Support for the IMPRS has been requested through a proposal to the Max Planck Society.

IV.2. Public Relations

The project plan has been made available by Internet, and copies have been sent to everybody expressing interest.

Progress would be announced by emails to all users, press releases, Internet, conferences and proceedings. For each HALO campaign an additional Internet page would be established to inform the public. Efforts would be made to describe HALO projects in popular science magazines, newspapers and other media, e.g., through press releases associated with campaigns and major results. The Internet would also be used to establish a "flying classroom" from which schools, for example, can download information about the atmosphere, HALO projects and global environmental change. During measurement campaigns with HALO, the public would be able to monitor the progress through "quick-looks" of the results, including descriptions of the domain of the campaign, research topics, goals, pre-campaign modelling results and practical information such as flight tracks and meteorological and atmospheric chemical forecasts.

The International Max Planck Research School (IMPRS), would contribute to the communication of HALO research to the research community, students of schools and universities, and the general public, using modern communication technology.

The manager of the IMPRS would work closely with the HALO project leader at the DLR, to coordinate education and public relations activities.

A.V. Project Management, Location, Costs and Schedule

V.1. Project Management

The HALO project was initiated by the entire German atmospheric science community based on a meeting in Mainz in May 2000. Following this initiative the DLR and MPG took the lead in submitting the application for a major research facility investment.

To support these activities a preparation project for HALO was installed at DLR, by decision of the DLR board of directors of September 2000. The project structure may be revised by the DLR board of directors when the funding decision is made or when any other reason makes changes necessary. The main objective of the project is the preparation of a decision on the HALO investment and operation. This includes support for the proposal and evaluation of the technical, logistical and financial aspects of the HALO project.

The preparation project is performed in close cooperation with scientists of the DLR Institute of Atmospheric Physics, of the MPG and other institutions participating in the HALO proposal.

An advisory board (Wissenschaftlicher Lenkungsausschuss – WLA) has been established at the meeting in Mainz in May 2000. The WLA is responsible for all scientific questions concerning the HALO project and accompanies the work of the preparation project within the DLR. Ultimately, the composition of the WLA will have to be decided by BMBF and other funding agencies, in consultation with the user community. It should include members nominated by the presidents of MPG and HGF.

The WLA would evaluate the scientific proposals for the use of the HALO aircraft and would establish a priority list of the projects. In doing so, external advice would be acquired from international experts. The WLA would guide the HALO project leader and Flight Facility management in their decisions on the planning, performance and deployment of the HALO aircraft.

V.2. Location

HALO would be operated out of the Oberpfaffenhofen Flight Facility of DLR. The Flight Facility is located at the runway of the Special Airfield Oberpfaffenhofen with direct access to the Fairchild Dornier company. The length of the runway (2286 m) guarantees the operation of the HALO aircraft under all temperature/weather conditions.

The Flight Facility is equipped with an aircraft hangar of about 1500 m^2. However, this hangar is not large enough to accommodate the HALO aircraft. A new hangar has been designed, which will include modern laboratories and offices dedicated to the HALO users. The costs for a new hangar have been included in the HALO budget. The hangar and additional laboratories can be realised in the direct vicinity of the existing infrastructure with direct access to the apron and refuelling station and to the facilities of the flight department: mechanical workshop, avionics workshop, electronic workshop, calibration facilities; user offices and laboratories, departments for maintenance and aircraft documentation, aircraft operation and mission planning, flight-system engineering, sensor and data operation, meteorological forecast, inspection and quality control, headquarters and offices of the Flight Facility and flight operations.

The additional staff for HALO operation, maintenance, and user support would be integrated into the existing infrastructure.

The operation of an aircraft like HALO must take place in a facility that is approved by the national authority of the country where the aircraft is registered. In general this can happen in organisations which have been certified as operator (Luftfahrtunternehmen) and JAR 145 Approved Maintenance Organisations or Luftfahrttechnische Betriebe (LTB). For modifications a license as Approved Design Organisation (Entwicklungsbetrieb) is necessary. The DLR Flight Facility satisfies all legal and organisational requirements.

The vicinity of both airfields, Augsburg and Munich, as alternate aerodromes is advantageous for operations. In case of choosing the Global Express from Bombardier, the vicinity of Fairchild-Dornier as a Bombardier service centre gives an extra benefit regarding service and maintenance availability.

V.3. Costs

For the intercontinental usage of HALO with 440 flight hours p.a., a cost volume of 3.8 Mio € p.a. is foreseen, including minor enhancements of instrumentation.

The number of personnel of the Flight Facility involved in the preparation of a HALO-campaign can easily increase up to 20 persons or more. But due to synergetic activities of the permanent staff of 31, the extra staff needed for the HALO operation can be limited to a maximum of about ten employees.

If HALO was operated from DLR Oberpfaffenhofen, there would be no specific need to re-allocate existing personnel.

Cost overview:

Total Investment, valid August 2001	97,0 Mio €
Planning and project Management costs, valid Aug. 2001	1,4 Mio €
Budget for initial 6 years operation, 6 x 3,8 Mio € ,4% p.a.	29,4 Mio €
Reserve for non foreseeable risks and miscellaneous	5,0 Mio €
Total estimated costs for acquisition and six years operation, no risks; valid for decision in 2001	**132,8 Mio €**
escalation for funding decision after Mar 2002; ca 4 % p.a.	ca. 6 Mio € p.a.

These costs are structured as follows:

Budget request for acquisition of aircraft and infrastructure (years 2002-2005):	
Green aircraft new (Price July 2001; valid for contract until Mar. 2002), 36,5 Mio US $; 0,85 US$ /€	43,0 Mio €
Modifications and basic sensor installation, according to list (ca. 100 % of the green aircraft)	43,0 Mio €
Infrastructure and technical basic equipment, (Hangar, user rooms, ground equipment, special tools etc.)	6,0 Mio €
Special scientific Instrumentation to be agreed by WLA	5,0 Mio €
Total estimated Investment, valid August 2001	**97,0 Mio €**
escalation for funding decision after Mar 2002; ca 4 % p.a.	4,0 Mio € p.a.
Reserve for non foreseeable risks and miscellaneous	5,0 Mio €

The planning costs for elaborating the final specifications, evaluation of proposals, monitoring of aircraft and modification realisation, development of basic sensors and infrastructure as well as managing the acceptance procedures are calculated as follows:

Budget request for planning (2001-2005):	
Personnel costs (ca 12 MY)	1,3 Mio €
Consumables (Travel and subsistence for Management and WLA, consulting etc.)	0,6 Mio €
Planning and project Management costs, valid Aug. 2001	**1,9 Mio €**
Contribution by DLR: one man-year from Institut für Physik der Atmosphäre and from Flugbetriebe each for 5 years	-0,5 Mio €

The operating costs are calculated using a deployment scenario of 440 flight hours and 220 occupation days per year. They include all additional direct costs for the operation of the aircraft with all user support functions. The structure of the operating costs is as follows:

Budget request for initial Operation phase 2004-2009:	per year
Personnel: Pilots, Mechanics, QS Engineers, Sensor- and Data-handling, user support, Campaign logistics, etc	0,6 Mio €
Consumables for aircraft disposal: Insurance, Registration, Time depending maintenance, Repairs,	1,0 Mio €
Consumables for aircraft operation: Fuel, Maintenance, ATC and Landing fees, etc	1,2 Mio €
other campaign costs of HALO flight operations: Travel costs, small parts, Transports. Rentals and Insurance for campaign logistics; Certification of scientific installations, etc.	0,5 Mio €
Consumables for user instrumentation and user support to be agreed by the WLA	0,5 Mio €
Total Budget for Operations per year, Valid Aug 2001	**3,8 Mio €**

MPG and DLR are applying to BMBF for financing of the additional investment and operation costs for HALO. This application also covers the overall cost of the HALO facility, including the preparation phase.

An apportioning of the HALO financing between HGF, MPG and DFG is not feasible at present.

HALO would become part of the DLR Flight Facilities department, which is financed through DLR institutional funding and external resources according to the usage of the existing aircraft.

It would be desirable that part of the costs may be covered by the EU within the 6th framework programme. However, until now this programme foresees no direct contributions to investments in research infrastructure. The same is true for the European Science Foundation (ESF), which also has no resources for investment programs on European infrastructure development.

The scale of the new facility would be of European dimension and it is planned to also offer the HALO use to the international community, notably through European programs. The EC is expected to provide support for users from outside Germany for using the HALO aircraft, similar to the STAARTE and CAATER projects. Moreover, HALO would become part of EUFAR (European Fleet for Airborne Research). These developments might contribute to reduce the operational costs or contribute to increase the amount of flight hours for European users, however, these contributions cannot yet be quantified.

V.4. Schedule

The use of the HALO aircraft for specific projects would be planned annually, for as far ahead as possible (likely 2-3 years). The annual schedule of flight operations would usually be set up by November for the coming year, with minor modifications during the year of operation. The following table serves as a prototype mission planning for any year of HALO operation.

	Number of flights	**Flight hours per mission**	**Total flight hours**	**Days of operation during Mission**	**Days of pre- and post-mission access**
Two aircraft campaigns in Europe (4 weeks each)					
Ferry flights	2	3	6		
Mission flights	10	5	50	26	5
Σ			**112**		**62**
One aircraft campaign in the tropics (4 weeks)					
Ferry flights	2	12	24		
Mission flights	10	5	50	26	5
Σ			**74**		**31**
One aircraft campaign in the Arctic region (4 weeks)					
Ferry flights	2	4	8		
Mission flights	10	5	50	26	5
Σ			**58**		**31**
Global deployment (4 weeks)					
Mission flights	12	8	96	26	5
Σ			**96**		**31**
Five smaller aircraft campaigns based from Germany (2 weeks each)					
Mission flights	5	4	20	10	3

	Number of flights	**Flight hours per mission**	**Total flight hours**	**Days of operation during Mission**	**Days of pre- and post-mission access**
Σ			100		65
ΣΣ			**440**		**220**

The HALO project foresees an initial operation period of six years. The lifetime of such an aircraft is about 25 years and the necessity for a extension of HALO operation is likely.

A specific planning of the sequence of flight missions for the various scientific questions has not yet been established. Specific HALO projects have to be planned in coordination with research proposals, e.g. to the EC. Based on DLR's experiences from the past, such planning should be possible about 2 years prior to the first HALO operations. For HALO operations starting in 2007, this implies detailed planning to start in early 2004 with decisions on the first specific missions during 2005.

B. Statement and Recommendations

B.I. Field of Research

Atmospheric science is essentially an observational science and increases in understanding are often limited by the lack of observations. The ability to make the required observations on the necessary scale is the prime justification for a facility such as HALO which would be capable of simultaneously measuring a comprehensive set of chemical species in situ, together with remote-sensing by LIDAR of critical species from the surface to the altitude of the aircraft. This should allow closure on a range of outstanding issues.

The main scientific questions to be addressed initially by HALO would include the complex linkage between the chemistry of the atmosphere and climate, also the influence of expected climate change on atmospheric composition and atmospheric motion, which disperses pollutants of many types. It is vital to validate the models of chemical composition and transport which are used for policy purposes to predict the state of the atmosphere in the 21st century. HALO would provide essential data here on the individual processes which are assembled together in global construct chemistry-transport models on a global scale of latitude and longitude up to altitudes of 15 km.

Another major question to be addressed by HALO is the interaction between the atmosphere and the biosphere, both the terrestrial biosphere and the marine biosphere. The biosphere has largely created the atmosphere over geological time and today it represents the major natural source of emissions of many gases and particles into the atmosphere. The study of the extent of perturbation of the atmosphere by anthropogenic emissions on a global scale must be carried in tandem with a similar study on natural emissions. HALO would provide an ideal opportunity to link these two activities across the world.

A third major question concerns meteorology and weather prediction. The main uncertainties in this area are associated with the presence of clouds in the atmosphere and the occurrence and intensity of precipitation, which is very difficult to predict with any confidence. This is particularly important in the case of intense precipitation which causes floods leading to loss of life and destruction of property. It should also be stressed that the major uncertainties in current climate models are concerned with the role of clouds and the possible feedback between clouds and climate. Clouds may even act as a thermostat maintaining atmosphere temperatures within a relatively narrow band ever since the atmosphere was first formed. Much more experimental data is required to test this hypothesis.

The fourth science question concerns technological development, specifically development of new instruments to measure important chemical species and physical parameters required by models. It is to be expected that the proposed studies will lead to further questions in the field of atmospheric science as understanding improves. Further applications are also to be expected as new technology is developed for use on high-altitude, long-range aircraft.

B.II. Scientific Program

Nine major research themes are addressed in the proposal for HALO. Their relevance and importance stem from the fact that increasing anthropogenic effects can be observed in some of the processes, which will change the atmospheric composition and the climate.

The nine major problem areas can only be resolved with the help of HALO. There may be other pressing problems whose solution could be accelerated with support from HALO measurements, which are also being discussed in the international scientific community.

Gravity from HALO combined with precise (laser) altimetry can provide bathymetric data that could, for example, image seamounts and other features on the order of

5 km in diameter (1 km with new technological developments), which would reveal much more about the ocean floor than is presently known. Similarly, magnetic features would be enhanced in a HALO survey over that which is obtained by satellite.

HALO capabilities could be utilized by those international organisations that are concerned with surveys of land use and soil moisture, where again future satellite data may not provide the required detail. One example where precise data are needed is given by restrictive measures taken by the European Union for the food production. Another is related to forecasts of harvest yields. Furthermore, the use of long distance flights, as provided by HALO, for research on forecasts of extremely high waves over various regions of the oceans and the causes of them should be investigated. Such waves often cause heavy damage to commercial vessels or even losses. Thus more precise forecasts might help to reduce losses.

The proposal describes ways where in particular direct and remote measurements with an aircraft of long endurance and high cruising heights, HALO, would play a key role as a platform for complex instrumental deployments. It must, however, be understood that HALO data alone cannot necessarily solve these problems. Rather, they need to be analysed in conjunction with other data available from satellites and existing ground-based networks as well as with the wealth of atmospheric circulation models that have been developed with different scales of resolution in space and time. These latter data sources do not provide the regional and local details which are required to understand the above-mentioned processes.

The German scientific community, represented by this proposal, has superior ability, indeed excellence, in these endeavours.

The proposing community has established sequences of competitive programs and projects which assure international collaboration and coordination from the beginning. HALO would become an important component in international research activities, which in fact cover the whole globe as outlined in programmes, such as the WCRP (World Climate Research Programme) and the IGBP (International Geosphere and Biosphere Programme).

B.III. Technology

The envisaged cruising altitude of 50.000 ft and an endurance of 8000 km represent a significant major improvement in airborne measurement capabilities. The aircraft is commercially available and has a multipurpose design. The technology, therefore, is well proven bearing no risks associated with achievement of both the required ceiling and endurance, and the planned missions. It is definitely a correct decision to buy a commercially available aircraft. In addition to the previous arguments, maintenance costs would be much less than for a specially developed or rather rare aircraft such as ER-2 or WB-57F.

The necessary modifications for instrumentation and specific installation would slightly alter the performance characteristics but could be minimized by the proposed cooperation with operators of other aircraft.

Miniaturisation and automatisation of the instruments would enable a greater variety of instruments to be fitted, expanding the user base and the number of experiments that can be conducted. This would further facilitate an ongoing improvement of the research objectives and the required instrumentation. HALO would contribute to the improvement of airborne measurement technology and would become an interdisciplinary research platform of an international topmost quality level. The platform would offer a test bed for making measurements of benefit to the aircraft and communication industry. Examples are:

- ultraviolet radiation exposure monitoring,
- improvement of GPS related technologies such as precise altimetry with accuracy of 1 cm or better,
- test of communication components or links for later satellite installation, as HALO could fly above the level used presently for communication and as well above weather phenomenon of middle latitudes such as thunderstorms. Generally, HALO can be considered as a measurement platform between surface based and space borne observations.

The envisaged online data communication link between HALO and the ground is highly innovative as it increases the ease of flight planning, enhances the data dissemination, and enables its use by a wider scientific and even public community. The data link also allows transmitting data to the cockpit and makes HALO open for all communication tools available on the ground such as the Internet. Web cameras could open HALO to the public. This would foster the public understanding of science, a crucial milestone in the 21st century. Moreover, new cockpit information technologies could be developed and tested such as weather warning systems.

The facility is completely feasible. Most of the instruments planned for the initial fit already exist on the market and have been proven on other platforms.

There is no alternative for making in-situ measurements in the lower stratosphere along a prescribed route and having this operational range.

While no development of the aircraft flight envelope is likely, opportunity exists to upgrade and expand the scientific instrumentation to broaden the scope and the efficiency of airborne measurements.

DLR has made a screening of available aircraft which meet the requirements of ceiling, endurance and payload. The decision between the two aircraft which came out of this screening should be made by DLR on the base of technical, financial and operational requirements including safety aspects. The pilots should be involved in the decision.

However, the possibility of having an identical twin aircraft (Gulfstream) together with NCAR and eventually with an Asian partner as a third platform presents many advantages and bares some very important strategic as well as technological aspects, which should be seriously taken into account. Besides the significantly reduced modification costs over 20 million Euro there would be synergetic benefits of having identical instrumen-tation, shared R&D tools and reduced development efforts. Experiences could and would be shared among the pilots, payloads would be exchangeable and the cooperation between USA and Germany would significantly improve. It is more than evident that with HALO the United States and Germany would take international leadership in airborne measurement technology. Moreover, a new type of global observation strategy would be possible for the first time on identical time and spatial scales. This would be a major breakthrough for atmospheric airborne research.

The problem of certification of the Gulfstream in Europe is presently a weakness and steps should be taken to resolve this issue as soon as possible.

The German scientific community would get a platform for airborne investigations with an outstanding opportunity to foster and enlarge the internationally well acknowledged high scientific level in atmospheric research and to broaden it to a real earth observation system as a major contribution to earth system science.

HALO could replace the Falcon in every respect.

B.IV. Project Management, Location, Costs and Schedule

The project management of HALO is very good and effective.

The facility at DLR is unique in Germany and is recognized as one of the best in Europe. The staff at DLR is highly experienced in operating research aircraft.

The cost estimate which includes the funding for project management, purchase and modification of the aircraft, development of infrastructure and 6 years of operation is reasonable. The operating costs need to be covered by funds to be made directly available to DLR so that non-DLR users only need to apply for pure research funding excluding the cost of flight hours. The operation budget for 440 hours/year includes a realistic number of additional staff (10) which can be reduced if/when Falcon goes out of service. It is required that the HGF contributes to the operating budget. The investment costs could be reduced by about 20 million Euro if a decision is made by the summer of 2002 to acquire a Gulfstream. This is due to the fact that the cost of conversion of a Gulfstream will be reduced as it will be possible to carry this out at the same time as a similar conversion for a US institution.

For the projected start of HALO operations in 2007, the planning of scientific missions needs to start in early 2004. This requires that a decision on the realization of the project needs to be made in mid 2003 at the very latest. However, this is only possible if a letter of intent is provided by the funding agency to DLR to enable them to start negotiations with the aircraft supplier in the summer of 2002.

B.V. Users of the Research Facility

The HALO research aircraft and its science program is of immense interest to a great number of scientists and disciplines. This includes the entire atmospheric sciences community such as atmospheric chemistry, atmospheric physics, meteorology, climatology as well as the various fields of earth observation covering geophysics, biogeochemistry, oceanography, polar research, remote sensing and all kinds of environmental research. The scientific problems that can be addressed with HALO range from basic science to applied science and even to technological development and testing.

Thus, HALO is designed to satisfy the needs of a very big and varied scientific community. It is a multipurpose tool which opens totally new possibilities for experiments because of its long range and high altitude capabilities. For instance, remote and large areas such as Amazonia and the Arctic can be studied; access is provided to the upper troposphere/lower stratosphere as well as to huge and high mountain areas like the Himalayas. Apart from these new high altitude capabilities of HALO, the aircraft could also satisfy the needs of the scientific community that requires low altitude experiments. This flexible usage of HALO would be possible due to a flexible instrumentation which would be permanently adjusted to the specific flight campaigns. Consequently HALO and its science plan could and would be adapted to the changing requirements of the scientific community.

The HALO proposal is supported by more than 30 institutions including various institutions from universities, from Max Planck society and from HGF. There is also a growing European and international interest in this new research aircraft. This further underlines the international relevance of the HALO project.

To serve the needs of the interested scientific community, HALO would be operated as a „community research aircraft“. This implies that the usage of HALO would be competitive and that all projects would undergo the same peer review system. The HALO planning group proposed an operational flow chart showing how to define and organise the flight campaigns and how to allot flight hours to individual projects; the central institution in this procedure would be a Scientific Steering Committee (Wissenschaftlicher Lenkungsausschuss, WLA). The access to HALO should include the following steps:

- The users who plan to submit a project proposal should first consult with the WLA to get a preliminary feedback about the feasibility and relevance of the project.

- In a second step the proposal should be evaluated by external reviewers or by an external review panel. The reviewed project proposals should then go the WLA for final decision.

- The WLA should make a decision on the priorities of the submitted research projects and should design the flight campaigns. While the prime criterion should be the scientific quality of the project, the WLA should take care that the various institutions (including universities), various disciplines and young scientists have an equal opportunity access to HALO.

The WLA would be the link to the “DLR Flight Facility”, which would provide the technical management. It would also have to design a consistent data management system which makes the data acquired during flight campaigns available to a larger community. Because of the importance of the WLA it should be composed in such a way that the relevant scientific disciplines and the various institutions (in particular universities) are adequately represented. Moreover, at least one scientist from a foreign country should be a member of the WLA and serve as a link to European and international research programs.

Another important task of the WLA would be to develop research programs and structures that could attract European and other external funding.

Universities would be fully integrated into the planning and operation of the HALO project and would be represented in the WLA. Hence, Master, PhD and PostDoc projects should play a major role in the HALO science program and thus in the education and training of young scientists. While working with HALO, students and young scientists would learn how to plan, coordinate and operate big scientific projects, as team members they would be included in interdisciplinary and international cooperation, moreover they would be trained to conceive and develop complex experiments starting with the formulation of the scientific questions and ending with the technical implementation of the instruments. Another important training aspect would relate to the data processing and management.

The availability of the new research aircraft to universities would considerably increase the attractiveness of atmospheric and earth observation sciences for future generations. In this context it will be important that additional funding would be available for PhD programs. A proposal for the establishment of a Max-Planck Research School in atmospheric science has already been submitted to the Max Planck Society. Presently, plans are developed to use the HALO project as a nucleus to establish a DFG priority research program (DFG Schwerpunktprogramm) or a Collaborative Research Centre (DFG Sonderforschungsbereich).

B.VI. Transfer of Research Results

Present atmospheric research includes observations and numerical simulations. The measurements of HALO are expected to have a large scientific impact regarding a variety of actual research topics by either validating, extending or rejecting present theories and numerical model results. The outcome of these comparisons is difficult to predict because HALO would open a new window for atmospheric observations due to its unique properties of ceiling height, mission range and the possibility to measure simultaneously a large variety of chemical trace components and geophysical properties. It should be stressed that the scientific capability for validation of numerical simulations strongly benefits from the large number of simultaneous measurements of an air mass which can be performed by HALO.

Significant technical impacts are expected for developments to measure trace components in the atmosphere and atmospheric physical properties. The most significant progress would probably be related to the miniaturization and automation of instruments to be used in HALO because space is strongly restricted in airplanes. HALO could be used as a test platform for remote sensing instruments. It would also provide an excellent opportunity to test instruments that will be used in satellites. Another outcome could be the further development of the combined use of ground based and airborne measurements, e.g. for lightning detection. Other technical developments might be achieved in the field of new GPS technologies and possibly the use of new cockpit instruments. The platform of HALO could be used for further developments of data transmission including satellites.

C. Conclusion

The great importance of the research themes addressed in the proposal for HALO stem from the fact that increasing anthropogenic effects can be observed in processes, that are considered relevant for changes of the atmospheric composition and the climate. The major problems as identified in the proposal can only be resolved with the help of an innovative research aircraft like HALO.

The German scientific community representing this proposal has established sequences of competitive programs and projects which assure highest quality standards as well as international collaboration and coordination. HALO would become an important component in international research activities.

HALO would offer a platform for airborne investigations with an outstanding opportunity to foster and enlarge the internationally well acknowledged high scientific level in atmospheric research and to broaden it to a real earth observation system as a major contribution to earth system science.

The HALO research aircraft and its science program are of immense interest to a great number of scientists and disciplines. The scientific problems that can be addressed with HALO range from basic science to applied science and even to technological development and testing of e.g. innovative instruments. The aircraft would be a multipurpose tool which opens totally new possibilities for experiments because of its long range and high altitude capabilities.

Oberpfaffenhofen is the best location in Europe to run HALO.

The HALO project should definitively be realized.