COSMIC DUST AGGREGATION IN MICROGRAVITY
FLIGHT REPORT OF THE CODAG MODULE ON MASER 8

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ABSTRACT

The CODAG module was flown on-board the MASER 8 sounding rocket on May 14th, 1999 from ESRANGE (Sweden). The experiment 'Cosmic Dust Aggregation in Microgravity' proposed by dr. J. Blum (Germany) and prof. A.-Ch. Levasseur-Regourd (France) was performed with great technical success during 378 seconds of microgravity. This paper presents details of the design, manufacture and acceptance testing of the module and a summarized technical flight report is given. The module and ground support equipment were developed for ESA by Fokker Space and subcontractors NLR, IDA/TU-Braunschweig and DLR, under a contract with the Swedish Space Corporation, SSC. Part of the light scattering set-up in the module was made available for flight by CNRS.

Keywords: Microgravity, Astrophysics, Sounding Rockets, Microscopy, Light Scattering, Cosmic Dust

1. INTRODUCTION

The 'Cosmic Dust Aggregation' (CODAG) experiment aims at the investigation of Brownian motion-driven aggregation of model cosmic dust particles, injected into a low pressure environment and under microgravity conditions. As such, the early phase of particle aggregation in a proto-planetary dust cloud is simulated and studied. The experiment consists of two parts, under the responsibility of two PIs:

1) Observation of the aggregation process by using high-speed, bi-directional microscopic imaging while scanning through the dust cloud
   dr. J. Blum (Astrophysikalisches Institut und Universitätssterngewarte, F. Schiller Universität, Jena, Germany)
2) Measurement of intensity and polarimetric phase function of laser light scattered from dust particles and aggregates
   prof. A.-Ch. Levasseur-Regourd (Service d'Aéronomie du CNRS, Verrières-le-Buisson, France).

Both parts of the experiment build upon a history of several years. The German part was initiated in 1991 with a 'Columbus Precursor Flights' proposal. In 1993 a start was made with hardware developments, under DARA funding, for an analogous experiment that was performed inside the 'G-764' GAS container on the recent STS-95 Space Shuttle mission (29/10-6/11/1998). The French part is strongly supported by a series of 'PROGRA' parabolic flight experiments executed under CNES funding since 1994 in Caravelle and Airbus craft. In 1996 ESA awarded flight opportunity for a joint sounding rocket mission on MASER 8, which was at that time planned for April 1998.

The scientific objectives of both experiment parts can be found in recent papers by the German and French scientists (Refs. 1, 2). Preliminary details on the mission definition, flight scenario and the design of the module system with its support equipment were presented in previous ESA symposium proceedings (Ref. 3).

The development of the CODAG module started in November 1996 with a Phase A/B study that resulted in 'Mission Definition' and 'Module Design' documents in April 1997, after which the Phase C/D was initiated. A Critical Design Review was held in August 1997. Shortly after the start of Module Acceptance Testing at Fokker Space, a one year launch delay for MASER 8 was announced as a result of loss of the required MASER Service Module in an unfortunate rocket test flight. After that, CODAG acceptance testing proceeded at a much slower pace and included parabolic flight tests of the dust injection subsystem, so-called 'Levitation Drum Tests' and an extensive series of vacuum tests. A final Module Acceptance Review was held in March 1999, after which the system was shipped to SSC for MASER 8 payload integration, tests and, finally, campaign.

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2. EXPERIMENT LAY-OUT

The experiment is executed in two independent set-ups that simultaneously make a diagnosis of a cloud of 1 µm diameter silicon dust particles. The cloud is injected into a low-pressure (2 mbar) gas environment, inside a central optical 'vacuum' chamber, at the beginning of the microgravity period. A schematic representation of the experiment lay-out is given in Figure 1.

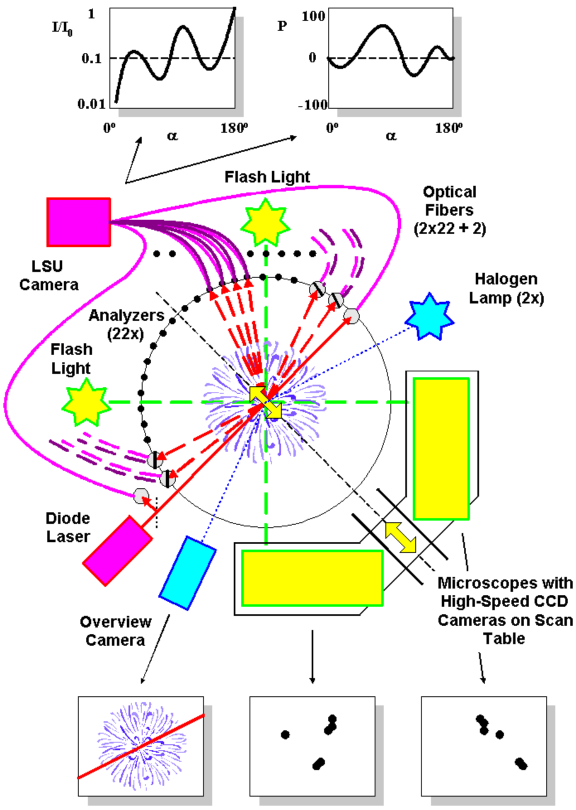

Figure 1: Highly schematic diagram of the CODAG experiment lay-out, with the set-ups for light scattering and microscopy around the central vacuum chamber with dust cloud

One set-up consists of two perpendicularly oriented microscopes with high-speed CCD cameras, mounted on a scan table. A large series of bi-directional images of the aggregating dust particles inside the joint observation volume of the microscopes is generated. Illumination is provided by two flash lights that are synchronized with the cameras. The images are recorded on a set of hard-disks inside the module and transferred to CD-ROM after the mission for scientific evaluation by the Jena group.

The other set-up is the 'Light Scattering Unit' (LSU), consisting of an assembly that collects scattered laser light in an array of 22 equidistant analyzers (*modulo* 7.5º in scattering angle range 0º-180º) that split the light according to polarization direction. Optical fibers transport the scattered light, and also part of the incident and transmitted light as references, to a CCD camera. The resulting scattering intensity and polarization phase curves are stored in the module and sent to the ESRANGE science center by telemetry. These data are then analyzed by the CNRS group.

Live video display of the deployed dust cloud is provided to the scientists by means of halogen lamps and a so-called overview CCD camera. A 'manual' tele-command option enables a second dust cloud injection, in case of an unsatisfactory automated first attempt.

3. MODULE AND GSE SYSTEM LAY-OUT

The complete experiment system, comprising the rocket module and its ground support equipment, is shown in Figure 2. Interfaces of the module in the MASER 8 payload with the MASER Service Module and TV Module, with the ESRANGE data distribution system and with the support equipment on the launcher (external cooler, vacuum pump, power supply) are indicated. The picture shows all PCs and video equipment involved. The PCs in the blockhouse are in a LAN configuration. Examples of the PC screen lay-out, consisting of several system and subsystem pages, are given in section 6 below. Tele-commanding is executed from the operator PC in the blockhouse.

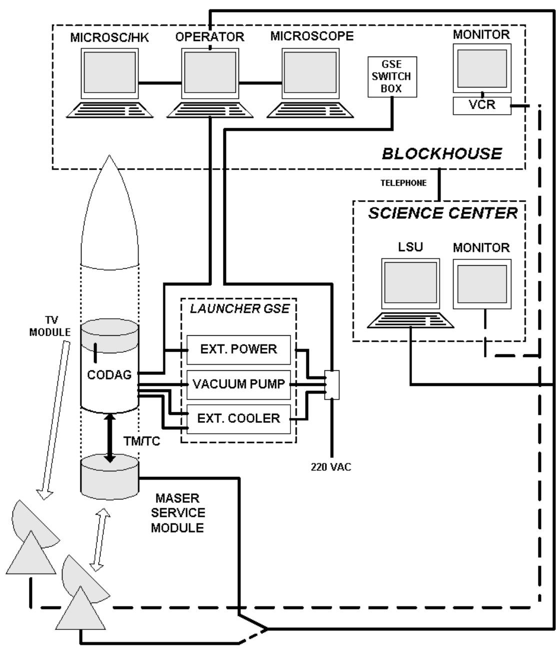

Figure 2: CODAG experiment system lay-out, comprising rocket module and ground support equipment

4. MODULE DESCRIPTION

The various subsystems corresponding to the experiment set-up described in the above are distributed over two experiment decks as illustrated in Figure 3.

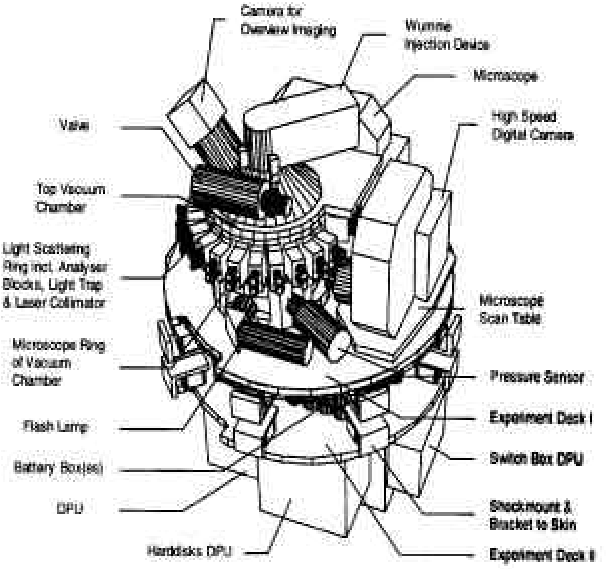

Figure 3: *Lay-out of the CODAG Module*

The upper deck carries most of the elements pertaining to the vacuum chamber, the microscopes and the Light Scattering Unit on its 'upper side':

Vacuum chamber subsystem, instrumented with temperature sensors (Smartec SMT-160) and two pressure sensors (Baratron 722A, 750B from MKS Ind.), consisting of four parts (Figure 4) that are bolted together using O-rings as sealing:

- Upper part or 'Lid', with two ports and three BK7 windows, onto which are mounted:
  - Dust injection device 'Wumme', complete with local electronics, manufactured by DLR (Cologne, Germany). The Wumme contains two charges for two independent dust cloud firings (HMX & Aluminum from Ensign-Bickford)
  - Vacuum valve (Balzers EVC 110M)
  - Two halogen lamps (Osram Decostar 35)
  - Overview CCD camera from Thalheim Spezial Optik (Pulsnitz, Germany)
- Light Scattering Ring, containing BK7 windows and red filters at all of the 22 analyzer locations and windows at the laser collimator (0º) and light trap
- Microscope Ring, containing windows for the microscopes and flash-lights
- Bottom part with concave inner surface

All parts were designed and manufactured by Fokker Space. The inner side of the rings was painted dull black (Electrodag 501 from Acheson Industries Inc.).

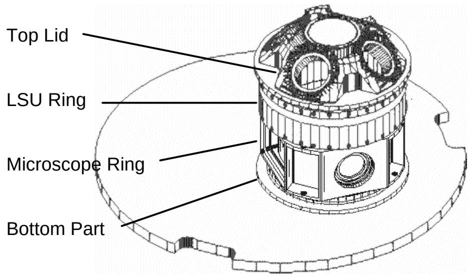

Figure 4: *The vacuum chamber assembly*

Microscope subsystem elements (Figure 5):

- Flash lights (Hamamatsu L4633) with optics and green filters, mounted onto the Microscope Ring at a 90º angle and shimmed to be focused at the middle of the scan-table range. The lamp sockets were potted for operation in vacuum
- Microscopes, 78 mm long working distance, magnification ca. 16x, depth of field ±50 ìm, resolution <1ìm. All optical elements were manufactured by Thalheim and were integrated with a folded light path into light-tight boxes at Fokker Space. Prior to flight, the microscopes were carefully (de-) focused through a slight shift of the tube-optics for correct operation in the vacuum flight environment
- High speed CCD cameras (Dalsa CA-D1-0256A), attached to the microscope boxes
- Scan-table with moving parts from INA (Barneveld, NL), opto-switches (RS 304-560) and motor/encoder set (Telerex 22S28/205E)

All mechanical parts were designed, manufactured and integrated by Fokker Space.

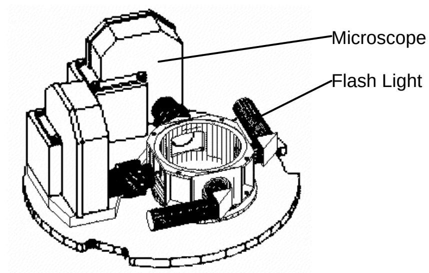

Figure 5: *The Microscope Subsystem*

Light Scattering Unit parts (Figure 6):

- 22 analyzer blocks (distributed over 360º), containing a Glan-Foucault polarization beam-splitter and a reflection prism, coupling lenses and fiber connections for each polarization direction
- Laser collimator block with intensity monitoring fiber connection
- Light trap unit with filters and fiber connection
- 24 optical fibers, secured onto a circular collar
- LSU CCD 'SPICAM' camera with ruggedly mounted fiber collection block

Most of these elements were designed, manufactured and made available for flight by CNRS Service d'Aéronomie.

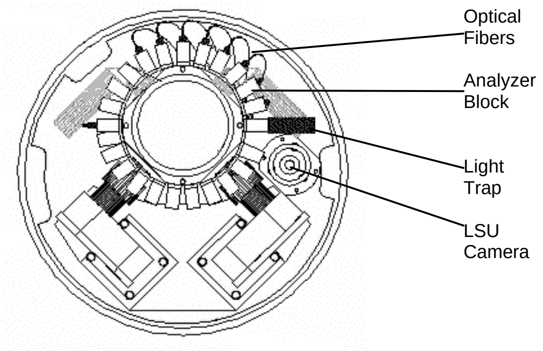

Figure 6: *Light Scattering Subsystem parts (top view)*

All other elements of the instrument are mounted on the lower side of the upper deck and at both sides of the lower deck. Most of these elements belong to the electronic system described below. Other elements are:

- The laser diode (SDL-2360-L2), with optical fiber to the collimator on the LSU-ring, rated 0.6 W at 830 nm, and its power driver (MPL from AMS Electronics). Temperature control of the laser diode was provided by a Peltier element
- Two flash light HV power supplies (Hamamatsu C3684), in vacuum tight boxes
- A cooling loop at the upper side of the lower deck

The two decks are both connected as well as mounted onto the module skin by a series of eight brackets with shock-mounts (Kayser Threde T8000 E01-4). The skin contains capped venting holes and the usual brackets and connectors for the electrical umbilical, the liquid umbilicals, a 'slide-off' vacuum umbilical and the payload feed-through cabling. A picture of the instrument and its module skin is shown in Figure 7. The hatch in the module skin was conceived in anticipation of (late) access operations to the instrument – eventually, no use was made of this provision.

5. ELECTRONIC SYSTEM

The electronic system of the CODAG module, with its embedded software, was designed, integrated and operated by NLR. It is organized very much according to the subsystems described in the above (Figure 8). A central role, both as communication node between all subsystems and the outside world (EGSE and MASER 8 system) as well as for power distribution, switching and monitoring, is taken up by the 'Service Electronics Box' (SEB; cf. Ref. 3). The employed distributed control scheme, based on 'smart subsystems' has been described before (Ref. 4).

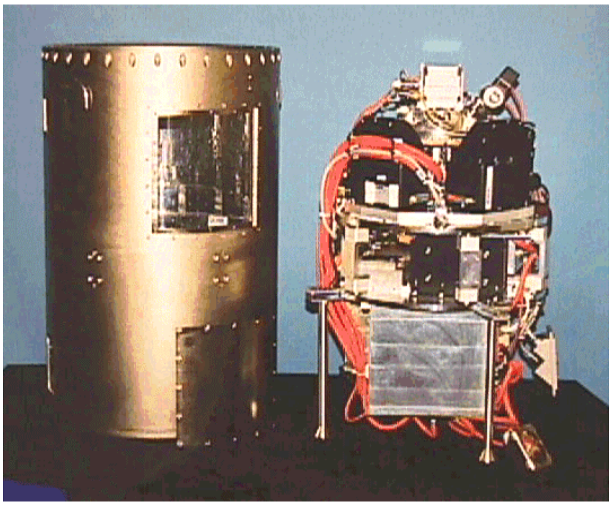

Figure 7: *The CODAG module, prior to integration of the instrument into its module skin*

Some electronic cards in the SEB were taken from an earlier mission (CIS-5 on MASER 7). However, the communication baudrates of the Service Processor Unit (SPU) and the Serial Experiment Interfaces (SEXIF) were increased to accommodate the large amount of data from the LSU. For this, also the on-board recorder (PROMCORDER) was upgraded. A new development for CODAG was the Service Module Interface (SMIF mk 3) to interface with the new MASER Service Module. A new feature of the SMIF is the telecommand function to execute commands from the operator during flight. On the ground and during flight the module is operated with the CODAG COmmand and Monitoring software (CODAGCOM). Figure 9 presents one of the pages of the user interface of CODAGCOM to the CODAG system. A second SMIF was included in the SEB to transmit the quick-look JPEG images from the microscopes to the ground. A dedicated PC receives this telemetry data via the SSC network and presents the JPEG images during flight (see Figure 2).

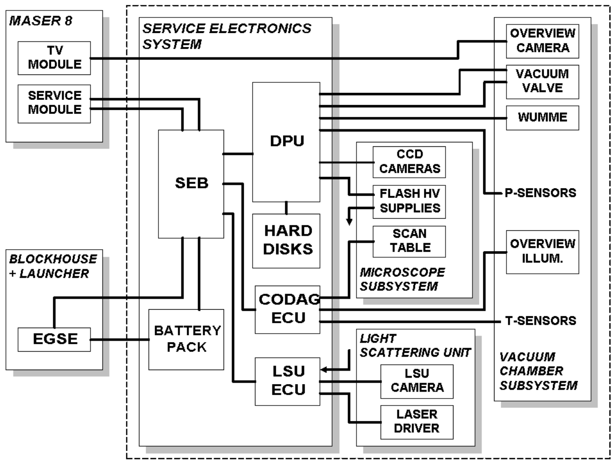

Figure 8: *Diagram of the CODAG electronic system*

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As shown in Figure 8, the three CODAG experiment subsystems are controlled by three electronic subsystems:

- The 'Data Processing Unit' (DPU), connected to a stack of four 1 Gbyte hard-disks (lower side of the lower deck). These elements were manufactured, complete with local software, by IDA of the TU-Braunschweig (Germany). The design was derived from hardware flown with the STS-95 GAS experiment. The DPU and hard-disk boxes are located on. Basically, the DPU synchronizes flash lights and microscopes and routes the images to the hard disks. Effectively, microscope images are generated at 100 Hz ('slow scan') and 200 Hz ('fast scan'), but stored at an approx. 80% lower rate. In total, some 15500 image pairs were obtained during the flight of the CODAG module.
- The LSU Electronic Control Unit (LSU-ECU) from NLR, containing also LSU camera electronics from CNRS (lower side upper deck). This unit provides control and read-out of the LSU laser and CCD camera, temperature control of laser and camera and, additionally, read-out of the pressure inside the flash HV power supply boxes
- The CODAG ECU, also from NLR (upper side lower deck), measuring four module temperatures and controlling overview illumination and scan table

Communication between the SEB and the electronic subsystems is based on RS485. Internal power is provided by a NiCd 28 VDC battery pack on the upper side of the lower deck (140 Wh; RS 1.7 cells from Varta).

6. SUMMARIZED FLIGHT REPORT

The CODAG module was launched on MASER 8 on May 14th, 1999 at 13:33 h local time. The microgravity phase started at t=70 s after lift-off and lasted 378 s. The dust cloud was injected into the vacuum chamber at t= 75 s. The success of the injection was witnessed from the live overview video display and from the observed pressure increase (dp= 1.95 mbar as compared to the 2 mbar required). The PC-screen overview page captured in Figure 9 shows the pressure step inside the small window. The re-injection option was abandoned.

From the PC displays it was thereupon observed that the module was executing its pre-programmed flight sequence of experiment actions in a completely nominal manner. The microscope bitmap image data was stored on-board and JPEG-data was sent to ground by telemetry. Light scattering data related to the measured intensity and polarization phase curves were recorded on-board and sent to ground by telemetry. The module system performed a nominal shut-down after the microgravity period.

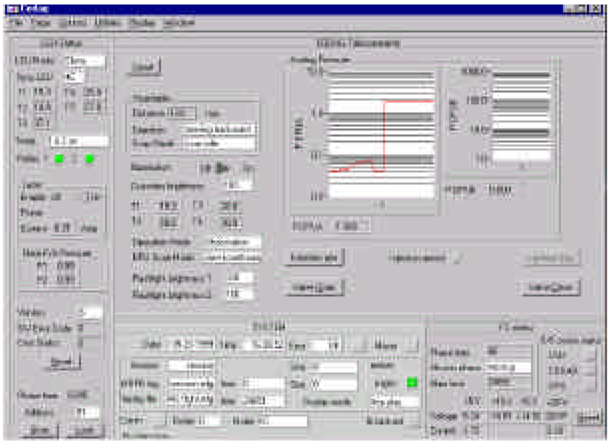

Figure 9: *PC overview page with 1.95 mbar pressure jump accompanying the dust injection shown in window*

The MASER 8 payload made a safe re-entry and parachute landing at 350°, 78 km downrange. Recovery by helicopter took 1 h and 32 minutes. After some celebration (Figure 10) the module was inspected, found to be in excellent condition and data read-out was started. Basically, experiment data was stored on diskettes, CDs and video tapes, which were thereupon sent to the experimenters for detailed scientific evaluation. A 'quick look' replay of the flight data files revealed that all subsystems had performed in a completely nominal way.

Figure 10: *The happy CODAG crew, and authors of this paper, after successful flight of the module and return of the payload to base*

Figure 11 presents an example of a microscope BMP-image pair read from CD, after applying some brightness and contrast enhancement. A particle aggregate can be distinguished, observed from two sides by the microscopes. From preliminary statements made by the PI it can be concluded that the complete image set contains sufficient and valuable data to make interesting science possible (Ref. 5).

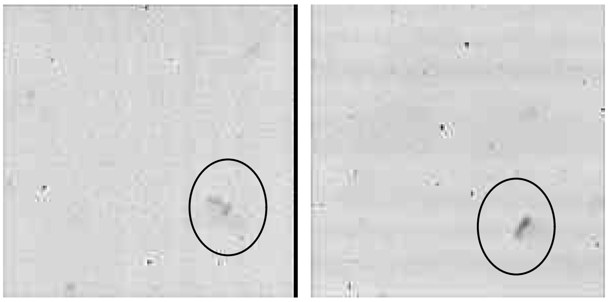

Figure 11: *Microscope bitmap images showing a particle aggregate, at t= 232 s after injection of the cloud, simultaneously observed by the two microscopes*

The obtained intensity and phase curves have been described by the PI to confirm dispersion of the cloud from the beginning of the injection. Figure 12 shows the LSU page at t=360 s into microgravity. The eight windows display the measurement values at various settings of gain and binning for the LSU camera. These curves are stated to give evidence for a constant temporal evolution in the properties of the scattering dust. They suggest the existence of a significant aggregation process after about 330 s (Ref. 6).

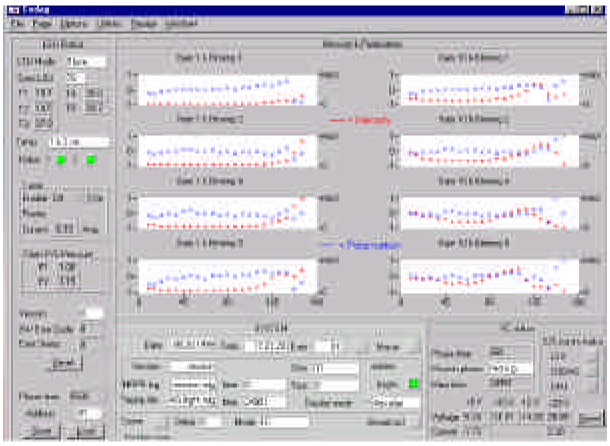

Figure12: *PC screen LSU page with light scattering and housekeeping data at t=360 s in microgravity*

7. CONCLUSIONS

The flight of the CODAG module on MASER 8 has been a complete technical success. The system has performed fully according to specifications and good quality data were obtained. Preliminary statements received from the scientists indicate that valuable scientific information has been collected. Currently, no plans exist for a follow-on mission within the MASER program.

8. ACKNOWLEDGMENTS

Early phases of the CODAG project were managed by Rob Postema (Phase B), who left Fokker Space, and Han Scholten (Phase C/D up to mid 1998), who accepted another position within the company. Martijn v.d. Meer made the Autocad drawings. The foundations for the CODAG electronic system were expertly laid by Louis Aartman and Hans Pauly of NLR; Hans left NLR after that. Björn Viethe of IDA/TU-Braunschweig and Dietmar Neuhaus of DLR/Cologne provided subsystems for CODAG and indispensable expertise to make them work as satisfactory as they did.

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